AN ENGINEERING GEOLOGICAL INVESTIGATION
OF BATTER STABILITY
WEAVERS OPENCAST COAL MINE - HUNTLY

A thesis
submitted in partial fulfilment
of the requirements for the Degree
of
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THESIS with 2 diagrams in back pocket

ABSTRACT

Cut slope batter instability of overburden in Weavers Opencast Mine at Huntly involves 0-65m succession of Waikato Coal Measures and Glen Afton Claystone of the Te Kuiti Group (Eocene to Oligocene), and a 15-65m sequence of overlying gravels, pumiceous sands, silts, clays and peats of the Tauranga Group (Pliocene to Holocene).

Field and laboratory investigations were conducted to determine the causes and mechanisms of cut batter instability. Field investigations included: detailed engineering geological mapping of the entire highwall at a scale of 1:1584 ; detailed batter logging and sampling of lower Tauranga Group materials ; and defect orientation surveys of Te Kuiti Group and Tauranga Group for stereographic analysis of failure modes. Laboratory investigations included: shear strength testing of the Te Kuiti-Tauranga Group unconformity contact and representative joint and bedding planes in the lower Tauranga Group; X.R.D. and chemical tests for clay mineralogy, grainsize distribution , atterberg limits, field moisture content, density and void ratio determination for Tauranga Group Materials.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND

Weavers Opencast Coal Mine lies within the Waikato Coal Field Region (Figure 1.1) and is located 80km south of Auckland on the western margin of Huntly Borough (Figure 1.2). The southern limit of the mine is bounded by the Rotowaro-Huntly Main Road and the western limit by Weavers Crossing Road.

Since 1984 Weavers Opencast Mine has expanded north and north-westwards of its original boundaries to meet the increase in demand for coal generated by the expansion of N.Z. Steel's Glenbrook works. The expansion of the coal mine involves the removal of 16 million cubic metres of overburden to enable an additional 2.3 million tonnes of coal to be recovered. At the end of mining (in 1993) the final position of the highwall will be within 150m of the shores of Lake Wahi.

Batter instability on a scale large enough to halt mining activity has been associated with the overburden materials in the advancing highwall. The increasing thickness of overburden northwards in the mine extension area, and the introduction in 1986 of a bucketwheel excavator and conveyor belt (potentially more vulnerable to disruption by batter instability), suggested that a greater engineering geological input was required for further appropriate highwall design.

In November 1985 the University of Canterbury Department of Geology negotiated a research contract (No. 3451) with the New Zealand Energy Research and Development Committee to investigate cut slope batter stability in Weavers Opencast Mine. This contract forms the basis for the present study.

1.2 THESIS OBJECTIVES:

The principal objectives of this study are:

1) to determine the causes and mechanisms of cut slope batter instability affecting Weavers Opencast Mine, West Huntly;
2) to develop engineering geological model(s) of cut slope batter instability;
3) to undertake initial numerical stability analyses based on the geotechnical data obtained.

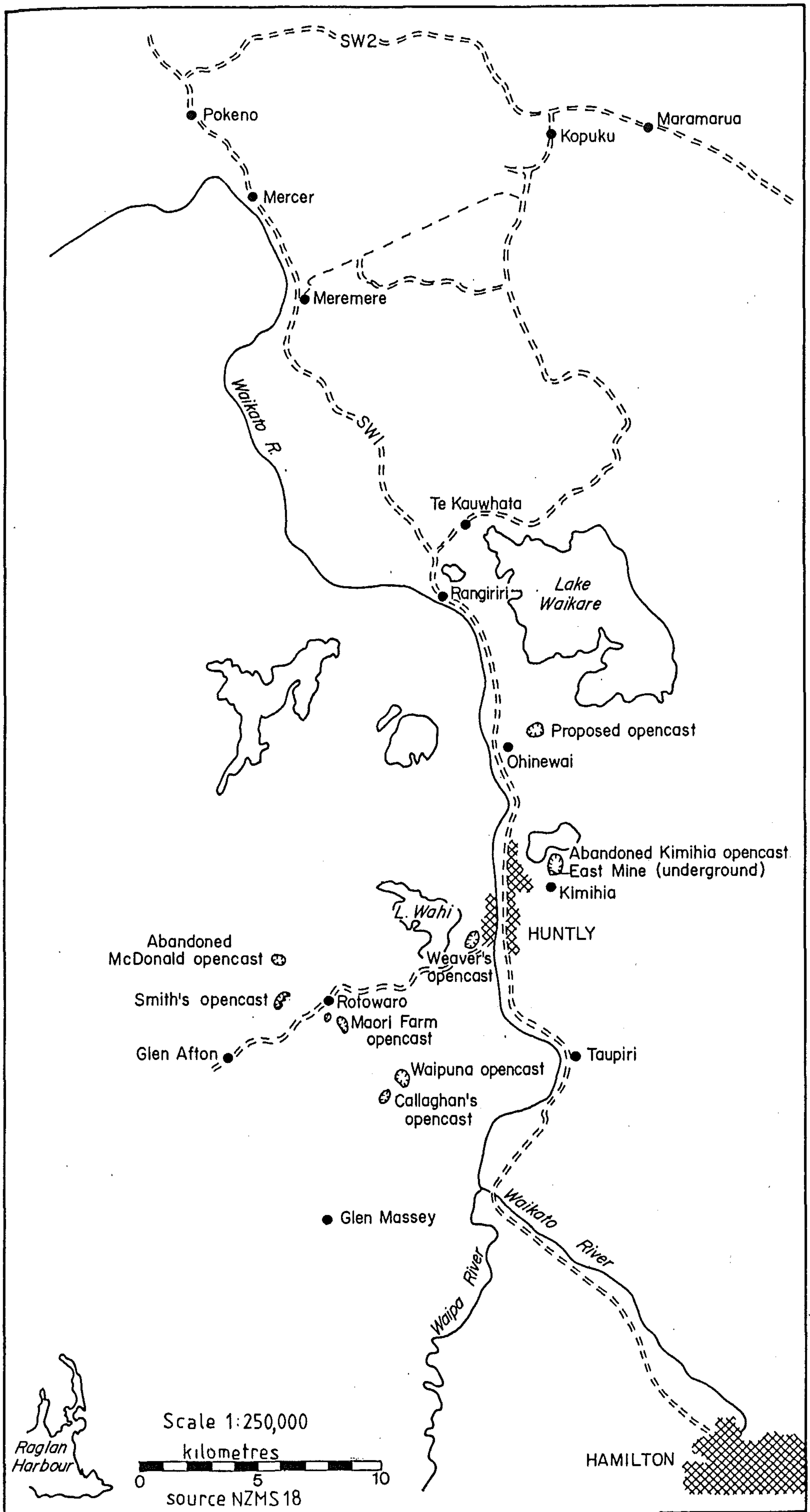


Figure 1.1 Waikato Coalfield Region

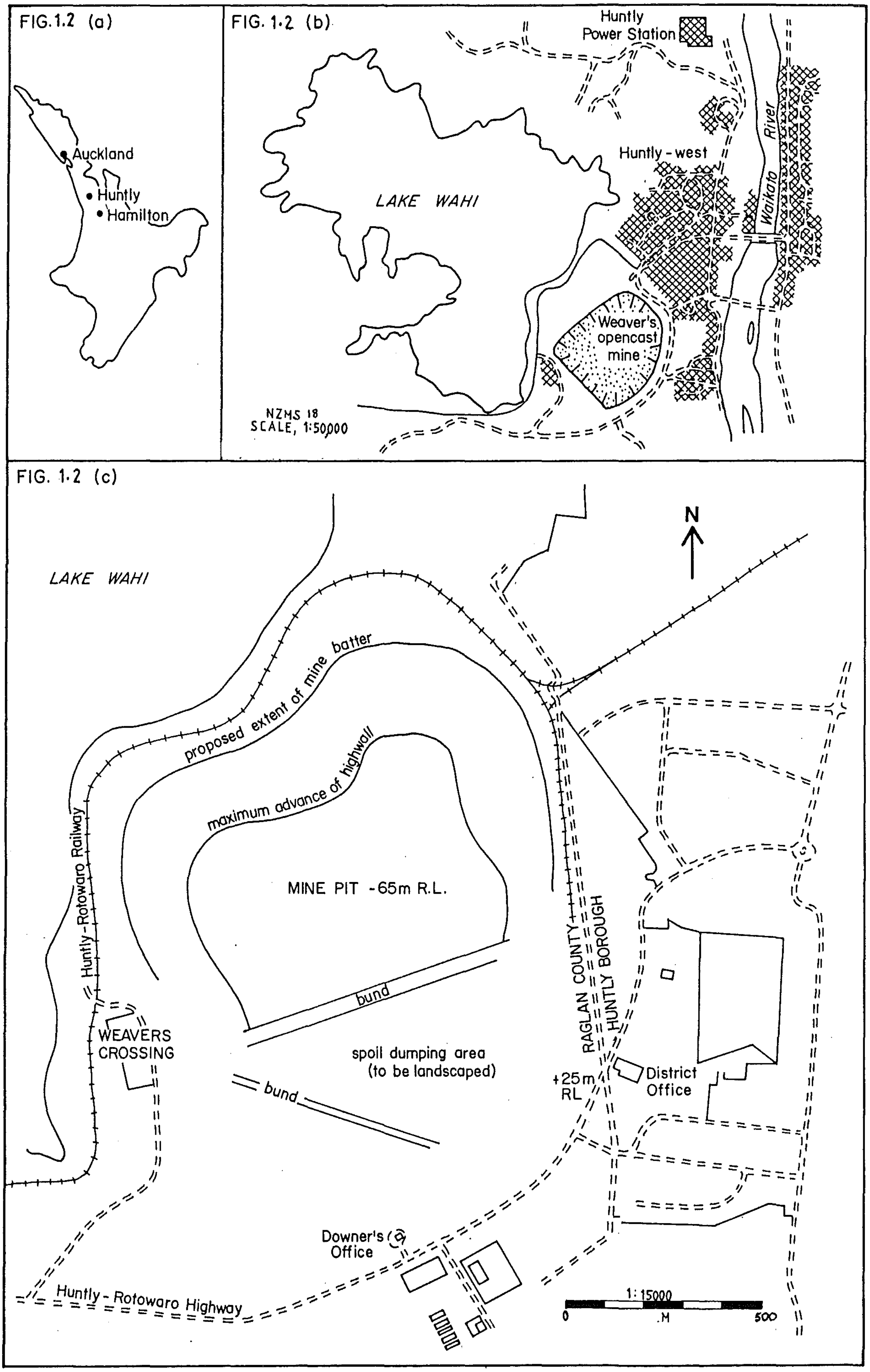


Figure 1.2 Weavers Opencast Mine General Location Map

source: Mines Division 1984

1.2.1 Scope of Research :

This study is not intended to provide detailed design or remedial measures, but rather to identify the causes and mechanisms of batter instability. From this information appropriate measures may subsequently be developed.

1.3 REGIONAL SETTING.

1.3.1 Introduction :

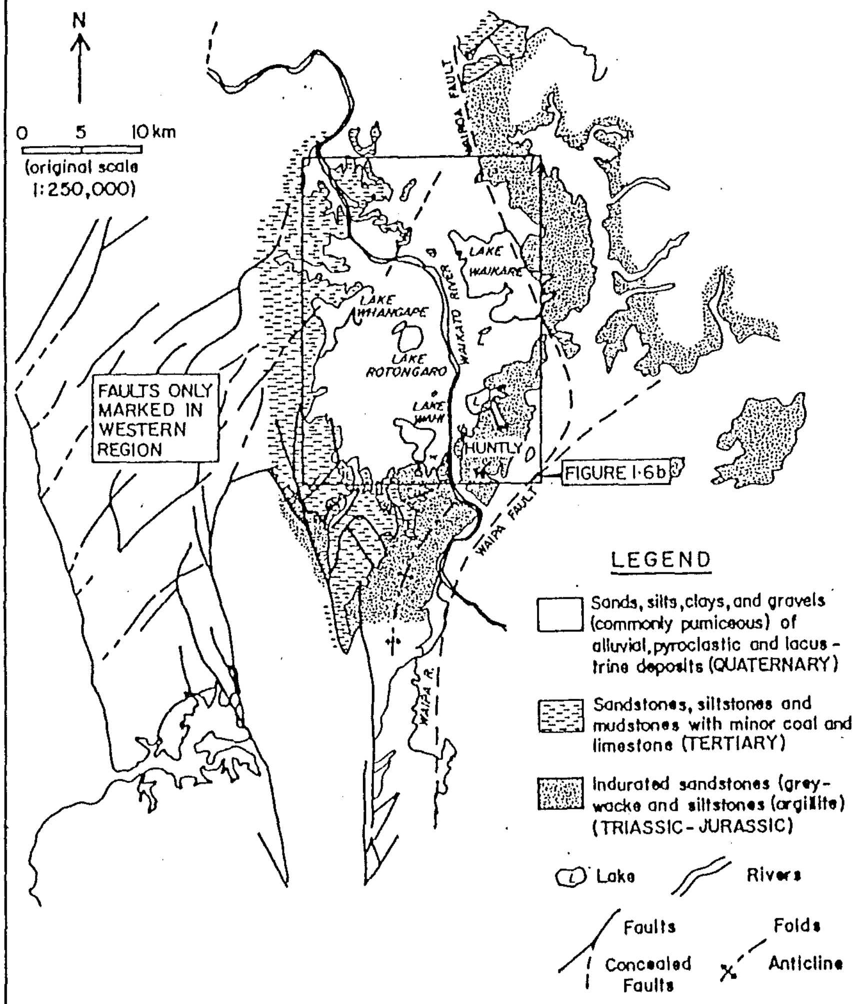
This review is based on the 1:250000 scale geological maps of Schofield (1967) and Kear (1960) , the New Zealand Geological Survey Bulletins of Schofield (1972) and Kear and Schofield (1978), and the geomorphological history of the Lower Waikato Lowland given by Selby (1982). The objective of this section is to define aspects of regional geology and physiography that are relevant to stability problems in Weavers Opencast mine. This approach is similar to that taken by Kelsey (1986), and borrows from his work.

1.3.2 Stratigraphy :

The stratigraphy of the Waikato area consists of Mesozoic basement rocks of the Hokonui System, overlain by Tertiary strata of the Te Kuiti Group, and an unlithified sequence of pumiceous and fluviatile sediments of Pliocene to Holocene age known as the Tauranga Group (Figure 1.3 and Table 1.1).

Basement rocks west of the Waipa River belong to the Newcastle Group which in the study area is dominated by indurated siltstones and sandstones of the Hakarimata Formation. Unconformably overlying basement are rocks belonging to the Te Kuiti Group, which forms a transgressive sequence deposited during Eocene to Oligocene times. At the base of the sequence lie the Waikato Coal Measures, a bedded sequence of carbonaceous mudstones and basal coal seams, which grade up into non calcareous mudstone, glauconitic sandstone, and non calcareous siltstone. Late Tertiary strata are increasingly calcareous and consist of siltstones, sandstones, and limestones.

Within the Huntly region Tertiary strata are unconformably overlain by Tauranga Group sediments, an unlithified predominantly pumiceous sequence of fluviatile, lacustrine and ignimbritic origin of Pliocene to Holocene age. The Tauranga Group has been subdivided into the Frankton, Walton and Piako Subgroups. Of the Frankton Subgroup only the Whangamarino Formation is present in the Huntly Region. The younger



Source: Schofield (1967) and Kear (1960)

FIGURE 1.3. GEOLOGICAL MAP OF THE NORTHERN WAIKATO.

(from Kelsey 1986 p11)

TABLE 1.1 Regional Stratigraphic Column;(after Kear & Schofield 1978)

Group	Subgroup and Formations and members	AGE	Lithological Summary
TAURANGA GROUP	PIAKO SUBGROUP		
	Taupo Pumice Alluvium	HOLOCENE	-loose current bedded, pumiceous course sands and grits interbedded with charcoal fragments.
	Hauraki Clay (1)	HOLOCENE	-estuarine clays of post glacial age.
	Hinuera Formation	H. / PLEISTOCENE	-loose, current bedded pumiceous coarse sands and grits interbedded with peats of late Glaciation Age.
	Hamilton Ash- Kauroa Ash	PLEISTOCENE	-brown, pinkish, halloysitic, sandy silty clays, commonly mottled, veined.
	WALTON SUBGROUP		
	Karapiro Formation	PLEISTOCENE	-highly weathered, pumiceous, coarse chyolite sands and current bedded grits interbedded with peats.
	Waeranga Gravels	PLEISTOCENE	-highly weathered greywacke gravels.
	Puketoka Formation	PLEISTOCENE	-pure pumiceous sands and silts, breccias and distal deposits of ignimbritic flows.
	FRANKTON SUBGROUP		
	Whangamorino Formation	PLIOCENE	-non marine gravels, clayey silts and lignites with rhyolitic pumice at top of formation.
	Koromatua Blacksand (1)	PLIOCENE	-unconsolidated non marine blacksnad and clay.
	Aberfoyle Siltstone (2)	PLIOCENE	-moderately consolidated non marine siltstone.
	Kaawa Formation (3)	PLIOCENE	-moderately consolidated shallow water marine sandstone with shell beds.
			Regional unconformity
TE KUITI GROUP	(4)	OLIGOCENE	calcareous glauconitic sandstones and siltstones, regressing into non calcareous shallow marine siltstones and sandstones with tuffaceous beds.
	Te Akatea Siltstone Whaiangaroa Siltstone Glen Massey Formation	OLIGOCENE	-calcareous marine mudstone, siltstones, and limestones.
	Mongakotuku Siltstone Pukemiro Sandstone Glen Afton Claystone	OLIGOCENE	-non calcoreous marine mudstones and sandstones.
	Waikato Coal measures	EOCENE	-carbonaceous mudstones, shales,siderite concretions and basal coalseams.
			Regional unconformity
NEWCASTLE GROUP	Hakarimata Formation	TRIASSIC	-indurated siltstones and sandstones.

Footnotes:
1. restricted mainly to Hauraki lowland.
2. restricted as subsurface formations to Hamilton Lowland.
3. restricted to Maramarua Coalfield.
4. restricted to south western portions of Hamilton Lowland, and small areas south of Rotowaro and Maramarua Coalfields.
5. basement rocks underlying most of Waikato Lowland and study area.

Walton and Piako Subgroup sediments which unconformably overlie the Whangamarino Formation, can be distinguished by their much greater pumiceous content and their more widespread occurrence in the Huntly region where they underlie the hill and lowland areas. Mantling the slopes near Huntly are ignimbritic deposits belonging to the Kauroa and Hamilton ash deposits (Kelsey 1986), which lie stratigraphically between the Walton and Piako Subgroups.

<u>1.3.3</u> <u>Structure</u> :

Newcastle Group Strata are deformed into broad N-NE striking anticlines and synclines of Pre-Tertiary age. Dips on the fold limbs average 45° but locally may be much steeper.

Newcastle Group and Te Kuiti Group rocks are block faulted and tilted with a regional dip of 5-15° to the N-NW. In the Huntly area fault blocks define coal field sector boundaries (Figure 1.4).

Tauranga Group sediments are sub horizontal but possess primary depositional angles seldom exceeding 5°.

<u>1.3.4</u> <u>Geomorphology</u> :

Huntly lies at the edge of the Lower Waikato Lowland (Figure 1.5), which is bounded to the south and southwest by the rugged relief (up to 300 metres high) of the block faulted Hakarimata and Taupiri Ranges. These ranges strike NE to SW and are drained by numerous streams that have incised narrow steep sided valleys. Of these the principal one occurs at Taupiri where the Waikato River and its tributaries have cut through the ranges to link the Hamilton and Lower Waikato Lowlands.

At the foot of the ranges Tertiary rocks form a more subdued relief of undulating hills. Slopes underlain by Tertiary mudrocks are often unstable and develop hummocked surfaces indicative of widespread mass movement, while the sandier more calcareous Tertiary units form steep slopes and bluffs.

The dominant morphologic feature of the Waikato lowland area are the subdued hills rising above a slightly undulating fluvial plain. These hills are the result of cyclic phases of stream aggradation and erosion (Figure 1.6). The oldest known phase of aggradation occurred with the deposition of the Whangamarino Formation and Walton Subgroup sediments which buried pre-existing landscape. Stream incision during the subsequent degradation phase produced a rolling hill and valley

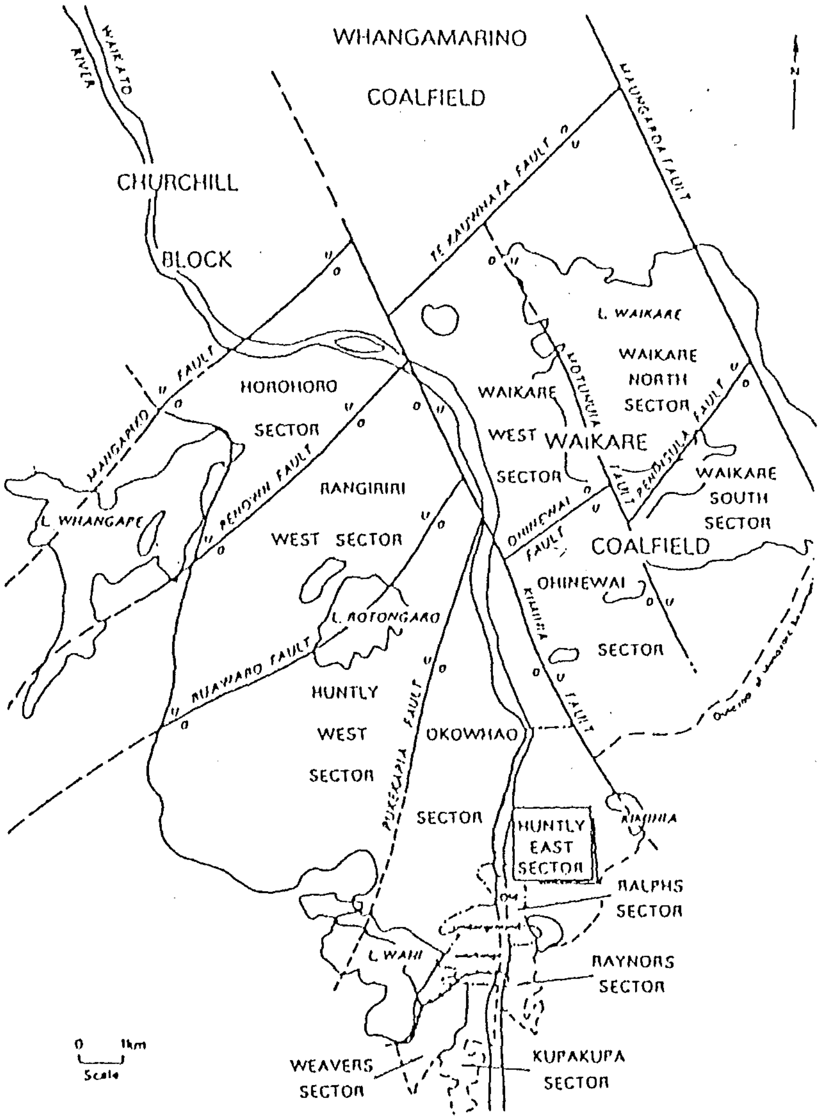


FIGURE 1.4 : FAULTS IN THE HUNTLY AND WAIKATO COALFIELDS (courtesy of N.Z. Geological Survey - from Gray and Daly, 1981)

(from Kelsey 1986 p11)

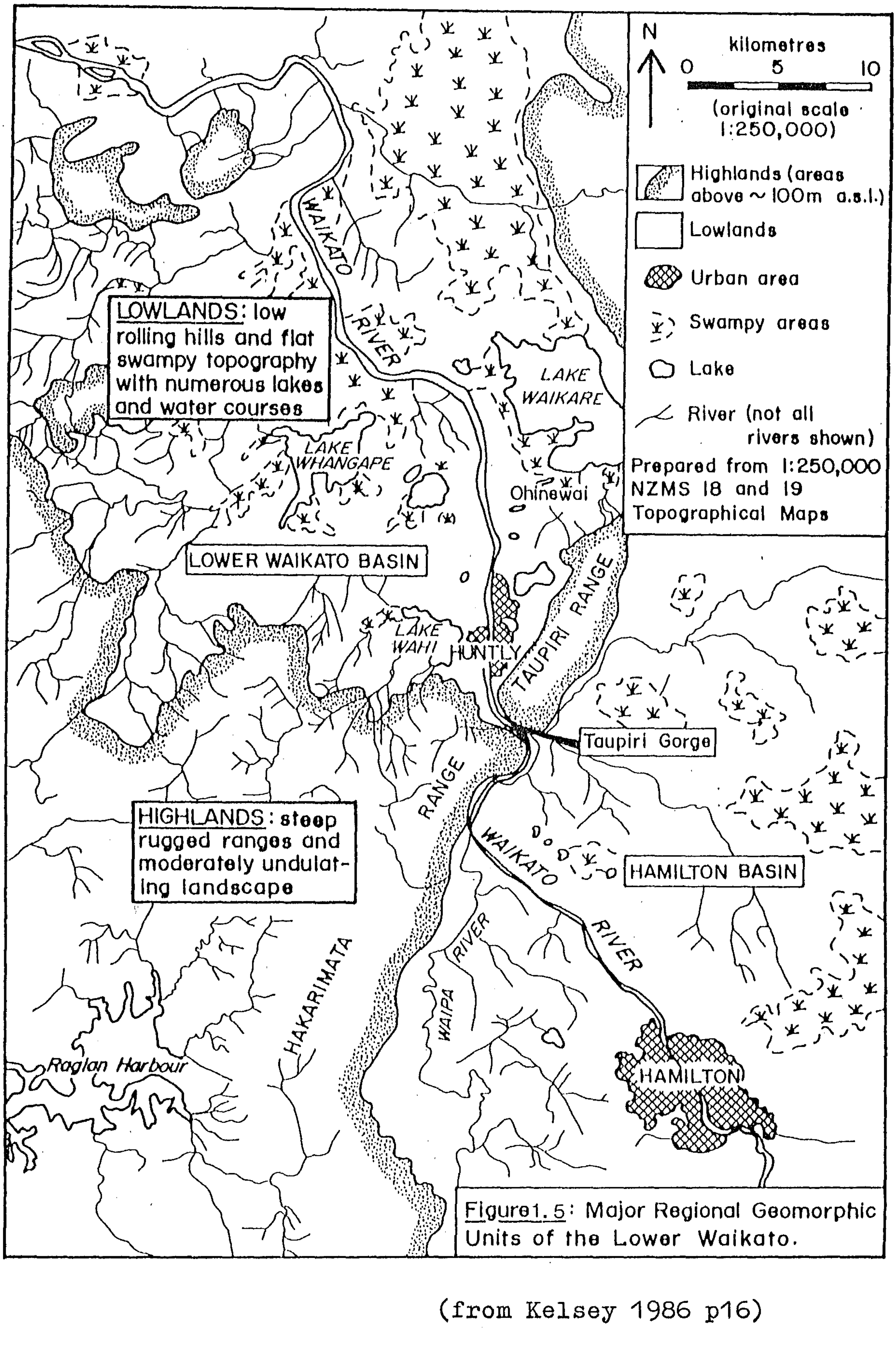


Figure 1.5: Major Regional Geomorphic Units of the Lower Waikato.

(from Kelsey 1986 p16)

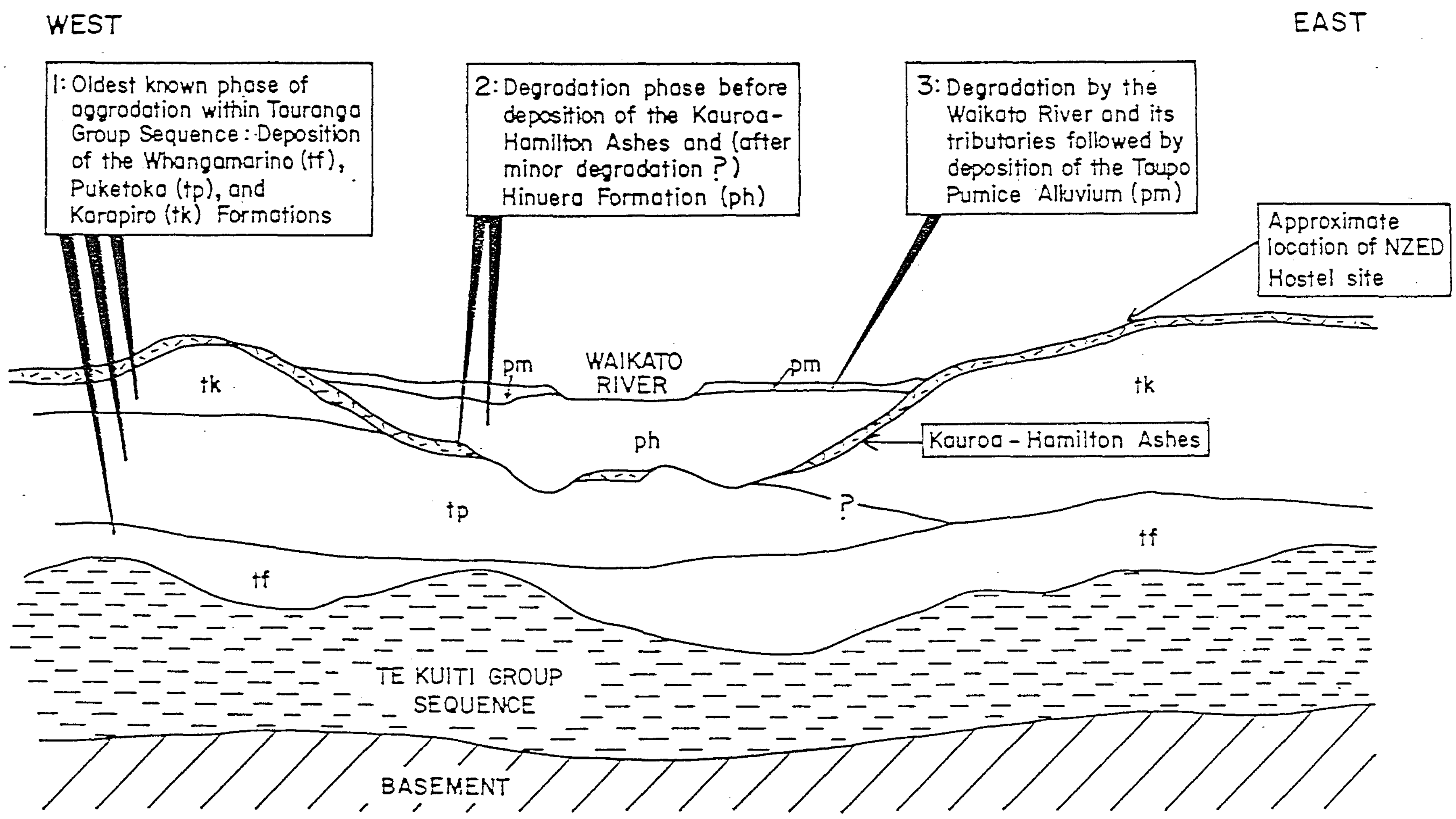


Diagram not to scale. Stratigraphic contacts approximate only. Construction is based on the regional study by Kear and Schofield (1978) and East Mine Tauranga Group interpretation by Todd (1982 b)

Figure 1. 6 : Schematic geological cross-section showing the geomorphic development of the Huntly area as determined by cycles of aggradation and degradation within the Tauranga Group sequence.

(from Kelsey 1986 p17)

topography, which was later mantled by the deposition of the Kauroa and Hamilton ash deposits.

Deposition of the Hinuera Formation produced the second major phase of aggradation. The resulting aggradation surface formed an extensive low angle fluvial fan of which only the northern most extension reaches the Lower Waikato Lowland (Kear and Schofield 1978). Hinuera aggradation dammed the upper reaches of many valleys, causing the formation of lakes some of which still exist today, examples being lakes Wahi and Kimihia in the Huntly area. Many lakes however, were subsequently infilled with sediments (mainly clay and peat). These lake sediments form most of The undifferentiated sediments of the Tauranga Group. Since it's deposition the sequence has been eroded by the Waikato River and it's tributaries. This erosion was temporarily interrupted when the Taupo Pumice Alluvium, related to the 186 A.D. Taupo Eruption (Wilson et.al.1980), was deposited forming the latest phase of aggradation. Taupo Pumice Alluvium deposits are mostly restricted to the main valley of the Waikato River, although north of Huntly between Ohinewai and Rangiriri it has buried the Hinuera surface (Kear and Schofield 1978).

Poor drainage of groundwater has resulted in the growth of extensive bogs that cover most of the Taupo Pumice aggradation surface.

<u>1.3.5</u> <u>Regional</u> <u>Hydrology</u> :

Climate in the Huntly area is mild with rainfall being evenly distributed throughout the year. Mean annual rainfall is 1273mm, with a range of 913-1592mm between 1940-1981 (Kelsey 1986). All surface drainage is towards the Waikato River and the surrounding lakes.

Basement and Te Kuiti Group materials are impermeable materials and are regarded as aquicludes, possessing mainly secondary permeability through rock mass defects (Schofield 1972). In contrast the highly pumiceous, uncemented sands and gravels of the Tauranga Group form an important source of groundwater in the Lower Waikato Lowland and contain at least two high yielding aquifer units;

i) The Upper Aquifer which contains the Hinuera Formation and Taupo Pumice Alluvium;

ii) The Lower Aquifer which contains the Whangamarino, Puketoka, and Karapiro Formations.

1.3.6 Summary:

The following regional factors are considered to be relevant to slope stability in Weavers Opencast Mine, these are:

1) The regional stratigraphy is dominated by three groups the Newcastle, Te Kuiti and Tauranga Groups each showing a distinctive structure and lithology.
2) The Tauranga Group succession is highly variable in lithology and shows complex field relationships.
3) Two high yielding aquifer units are present within the Tauranga Group succession.

1.4 THESIS METHODOLOGY .

The outline for field and laboratory programmes is summarized in figure 1.7, which is along the lines suggested by Hoek and Bray (1981) for slope stability investigations in opencast mines.

1.5 THESIS ORGANISATION.

Chapter 2 applies the information obtained from the regional study to the specific site geology of Weavers Opencast Mine. The stratigraphic, structural, and hydrologic factors considered to be relevant to batter stability in the mine are used to develop an engineering geological model for further investigation.

Chapter 3 discusses the laboratory investigations undertaken and the results obtained.

Chapter 4 analyses in detail the causes and mechanisms of batter failure based on the results obtained from chapters 2 and 3.

Chapter 5 presents an engineering geological model of the highwall summarising the causes and mechanisms of highwall instability. Factors that may contribute to future batter instability are indicated. Recommendations for further research are made.

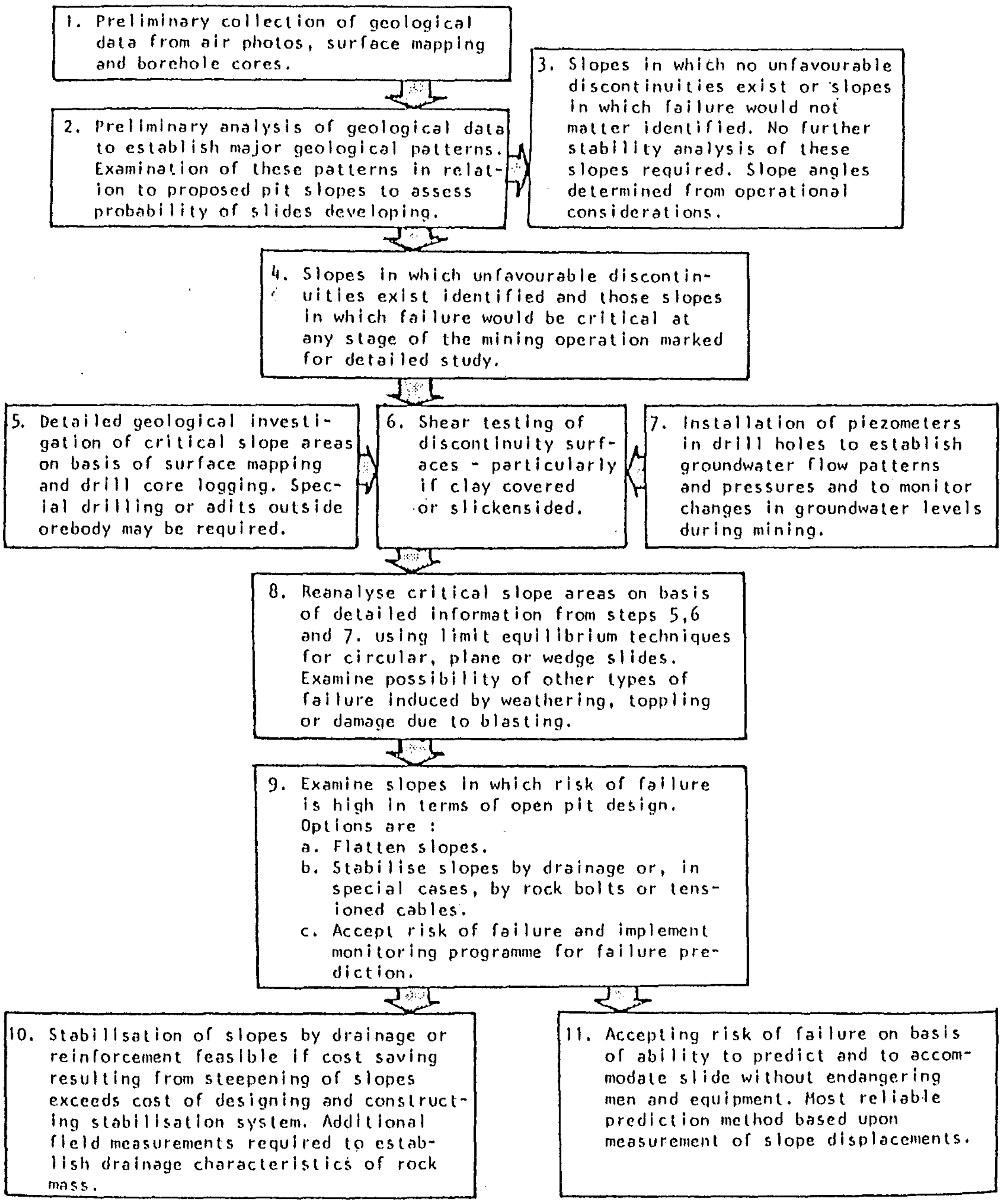


FIGURE 1.7: Analysis of the Stability of Slopes in Open Pit Mines.

(from Hoek and Bray 1981 p14)

CHAPTER 2
MINE GEOLOGY

2.1 INTRODUCTION

This chapter provides an engineering geological description of mine stratigraphy, structure and hydrogeology. Mine stratigraphy is based on the published work of Kear and Schofield (1978), and engineering geological mapping for this study conducted in the mine from December 1985 until July 1987. In addition borehole information from the mine extension area (Henderson 1983) is also incorporated.

Mine structure is assessed from defect survey data obtained. Data from defect surveys of the Waikato Coal Measures collected by State Coal Mine personnel (Hyde 1986) is also discussed.

Hydrogeology of the mine extension area is assessed from existing information (Alldred 1984a; Hue 1985; Hue and Delahunty 1986), but discussion is limited to those factors that are directly relevant to highwall stability.

Information obtained from these three sections is used to develop an engineering geological model of the Weavers Opencast Mine highwall summarising those factors relevant to batter stability.

2.2 MINE STRATIGRAPHY

The stratigraphy encountered in the Weavers Opencast Mine is summarised in Table 2.1; nine formations comprising three groups are mapped from exposures and borehole data. Rock and soil material field descriptions are based on the classification scheme of Bell and Pettinga (1984). This scheme was preferred to others; N.Z.G.S 1985, I.A.E.G. 1981, due to its familiarity, as well as its conciseness and graphical presentation.

2.2.1 Newcastle Group Materials:

Mesozoic basement rocks belonging to the Hakarimata Formation are not exposed in the mine, but borehole data indicates that the unconformity between Newcastle Group (Hakarimata Formation) and overlying Te Kuiti Group rocks of Tertiary age is located within 5-15m of the pit floor. This unconformity has up to 30m relief which is controlled by a buried ridge at -28m R.L. (Moturiki Datum), in the northeast sector of the mine, and a buried valley at -60m R.L. in the central and southwestern part of the mine. Engineering geological

TABLE 2.1 WEAVERS OPENCAST MINE STRATIGRAPHIC COLUMN.

		AGE	DESCRIPTION
TAURANGA GROUP	Undifferentiated Tauranga Group sediment (0-15m)	HOLOCENE	swamp and lake sediments consisting of lightly compacted, organic rich, clayey silt, silty clay and peat.
	Taupo Pumice Alluvium (0-8m)	HOLOCENE	fluviatile, loose, whitish cream, current bedded, highly pumiceous, silts, sands and gravels, with common charcoal fragments.
	Hinuera Formation (0-10m)	PLEISTOCENE	fluviatile, loose, yellow brown to grayish green, pumice rich, silts sands and gravels, displaying current bedding and fining upward sequences. Interbedded with discontinuous lenses of sandy silty and silty clay.
	Kauroa-Hamilton Asm (0-5m)	PLEISTOCENE	ignimbritic palereddish yellow and yellow brown sandy silts and halloysitic silty clay:
	Whangamarino Fm (0-65m)	PLIOCENE	fluviatile, stiff, bluish green, clayey silt with discontinuous bands of peat and wedge shaped lenses of silty sands and sandy silts Basal unit. fluviatile highly compacted sequence of greywacke gravels in matrix of pumice and quartzose rich muddy sands and muddy gravels.
	unconformity		
TE KUITI GROUP	Mangakotuku Siltstone (0-6m)	OLIGOCENE	Non calcoreous, massive weak, greyish green mudstone.
	Pukemiro Sandstone (0-6m)	OLIGOCENE	Glauconitic, massive, weak, greyish green fine sandstone.
	Glen Afton Claystone (0-15m)	OLIGOCENE	Non calcolcoreous, massive, weak greyish green, silty claystone.
	Waikato Coal Measures (0-45m)	EOCENE	moderately weak, dark grey to grey brown slightly carbonaceous mudstone, interbedded with brownish black carbonaceous mudstone, basal coal seams and siderite concretions.
	unconformity		
NEWCASTLE GROUP	Hakarimata Formation	UPPER TRIASSIC	indurated silt stone and sandstone.

(based on Kear and Schofield 1978; Henderson 1983) descriptions of this unconformity surface are very limited but suggest that the top of the Hakarimata Formation consist of highly weathered blue grey non calcareous siltstone.

In the Huntly East Mine the top of basement rock typically consists of a 5m thick clay rich weathered zone which grades into underlying highly indurated siltstones and sandstones (Kelsey 1986). Artificial exposures in road cuttings (Kear and Schofield 1978) suggest that the top of the Hakarimata Formation is typically highly weathered up to a depth of 15m.

2.2.2 Te Kuiti Group Materials:

The Tertiary sequence in the mine consists of a 40-45m thick sequence of Waikato Coal Measure strata, conformably overlain by up an to 15m thick sequence of Glen Afton Claystone (Cross Section Figure 1 Map Pocket).

The bedded coal measures exposed in the batter slopes are dominated by moderately weak, dark grey to grey brown beds of slightly carbonaceous mudstones alternating with beds of brownish black carbonaceous mudstone. Beds vary in thickness from a few centimetres to several metres with the carbonaceous beds more dominant towards the base of the coal measures succession. The sequence is interbedded at irregular intervals with very strong reddish brown siderite concretionary layers up to 30cm thick and continuous in the face for several tens of metres.

Two coal seams are interbedded near the base of the coal measures sequence exposed in the pit. The lower Kupakupa seam is characterized by considerable variations in thickness and dip direction over tens of metres. Henderson (1983) noted the seam thickness ranging from 2-8m in the mine extension area. Coal overburden thickness ranges from 45m thickness for the present opencast mine area to 85m for the extension area. The overlying Renown seam has an average thickness of 1m but locally reaches up to 4m in thickness. In some parts of the mine it has been removed by Eocene and Quaternary erosion.

The contact of the coal measures with the overlying Glen Afton Claystone is gradational over several metres and consists of a change in colour from slightly weathered, moderately weak, greyish brown bedded claystone grading into overlying greenish grey massive claystone. Borehole data from the mine extension (Figure 2.1) area indicates that the Glen Afton Claystone conformably grades up into 6m

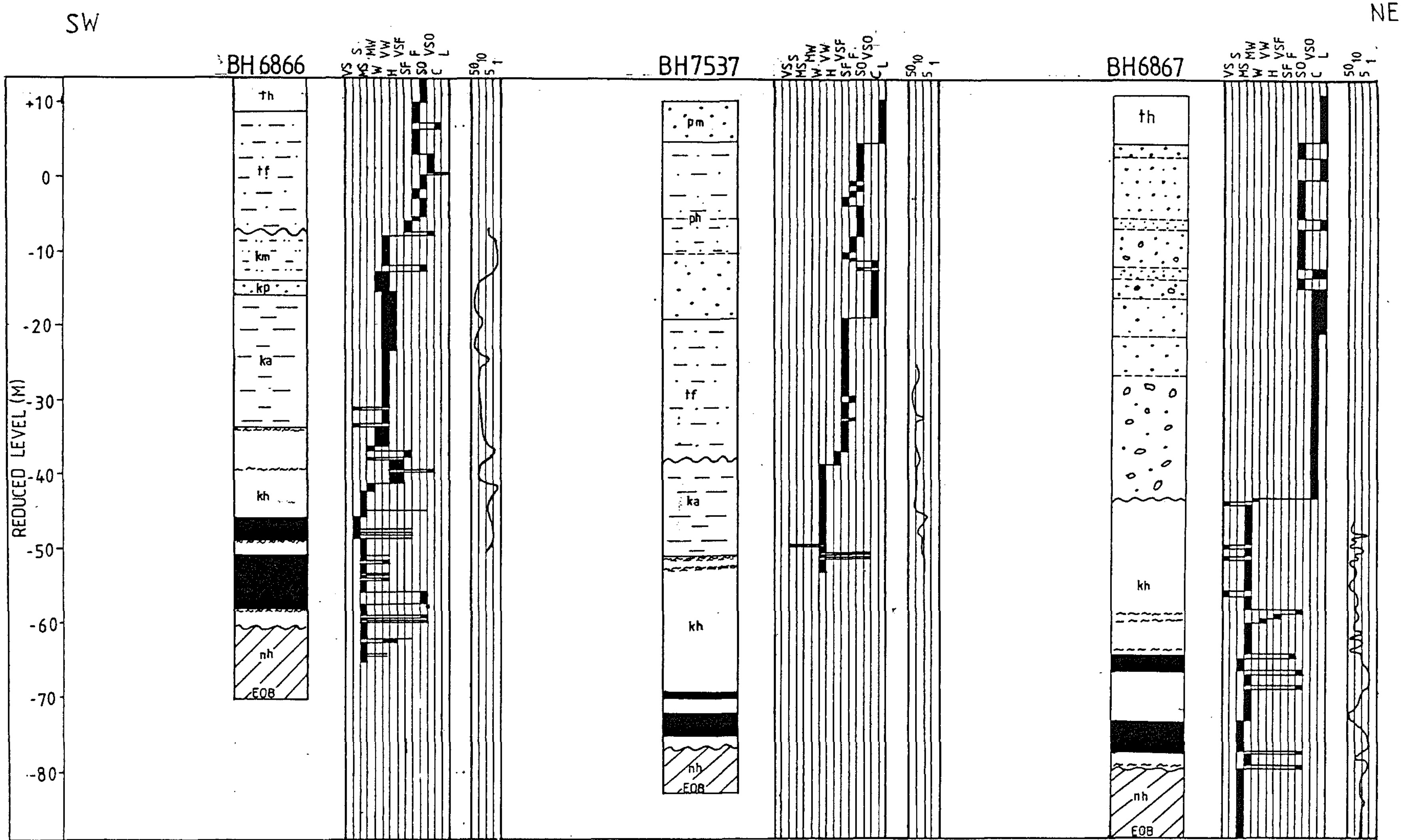


FIGURE 2·1 SUMMARY OF CORED BOREHOLES IN MINE EXTENSION AREA

pm = Taupo Pumice Alluvium
ph = Hinuera Formation
tf = Whangamarino Formation
th = Kauroa and Hamilton Ash Deposits
km = Mangakotuku Siltstone
kp = Pukemiro Sandstone
ka = Glen Afton Claystone
kh = Waikato Coal Measures
nh = Hakarimata Formation

thick Pukemiro Sandstone, consisting of massive and bioturbated glauconitic muddy fine sandstone, which in turn is conformably overlain by 6m thick Mangakotuku Siltstone, consisting of massive to sub horizontally laminated greenish grey mudstone. Tertiary marine materials are referred to as soft rocks (Riddols and Read 1980) which are slake prone.

The thickness of the Tertiary sequence in the mine area is controlled i) by the relief on the unconformable contact with Newcastle Group rocks at its base, and post depositional erosion at its upper contact, and ii) by the regional tilt of the strata to the north at 5°-15°.

2.2.3 Te Kuiti Tauranga Group Contact:

A principal objective of this study is to determine whether instability of cut batters in Tauranga Group materials is associated with this contact. The orientation of the unconformity surface with respect to the highwall, as well as the shear strength of materials along this contact are two factors that may influence the stability of the overlying Tauranga Group sequence.

In the SW of the mine area relief is dominated by a paleoridge ridge of Glen Afton Claystone striking NE - SW into the mine area Figure (2.2) subparallel to the orientation of the highwall. At the time of mapping the highwall cut across this ridge and the dip of the unconformity surface was about 5° out of the batter slope. Future mining activity will push the highwall north of this ridge, so that the contact will attain a more favourable dip orientation into the highwall of c.10°.

Glen Afton Claystone underlying the unconformity surface is affected by weathering showing discolouration and loss of strength. The effects of weathering sometimes extend to only a few centimetres beneath the unconformity contact but more commonly are visible up to 2-3m below it. Typically the material grades downwards from highly to moderately weathered, very weak pale bluish green silty clay (stone) into slightly weathered moderately weak , dark olive green, massive silty claystone.

In the central and northeastern sector of the mine area, the orientation of the unconformity surface is controlled by a major paleo valley striking NW-SE across the mine extension area (Figure 2.2). The Te-Kuiti- Tauranga Group contact in these sectors of the mine area dip into the highwall at 5°, and 20°-25° respectively. This dip orientation along the unconformity surface will be maintained with future advances

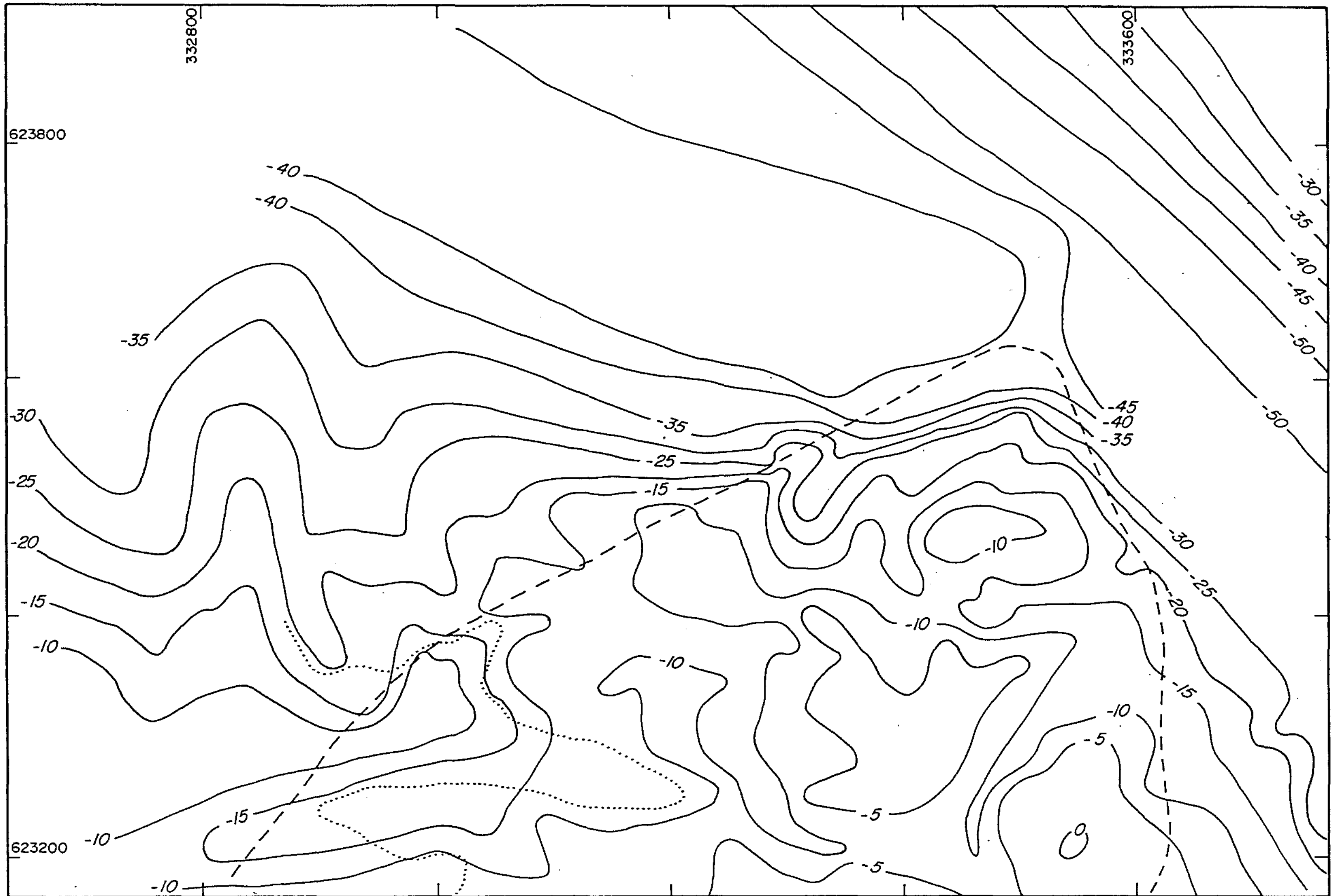


Figure 2·2 Structure Contours on Base of Tauranga Group (after Henderson 1983)

1:1,584 Original Scale

-20 Contour Lines (m RL)
Glen Afton Claystone 0m Contour
Edge of Batters, July 1986

of the highwall to the northwest and is thus favourable for mining activity. The contact between Tauranga Group and Waikato Coal Measures in the northeastern and central sectors of the mine is situated in a 15m high batter face dipping at 80°. Observations along the contact in this part of the mine were therefore more limited. However observations suggest that coal measures material underlying the unconformity contact typically consists of 0.1-0.5m thick , completely weathered, stiff to firm moderately plastic, silty clay, grading into moderately weathered, weak greyish white to brownish grey mudstone.

2.2.4 Tauranga Group Materials:

The major stratigraphic units recognised within the Tauranga Group sequence are the Whangamarino Formation, Kauroa and Hamilton ash deposits, the Hinuera Formation and the Taupo Pumice Alluvium. These units are described on the basis of engineering geological field descriptions using Bell and Pettinga (1984). Genetic qualifiers such as 'ignimbritic' and 'fluviatile' are used to distinguish Tauranga Group materials of different origin. This was first used by Patterson (1977) to describe ignimbritic materials in the Poutu Tunnel and was subsequently used by Kelsey (1986) to describe Tauranga materials in the Huntly East Mine.

At present up to 30m of Tauranga Group deposits is exposed in the Weavers Opencast Mine highwall. However, in the mine extension area this will increase to over 50m in the final north eastern batters, and 25-30m in the final central and southwestern batters, (Figure 2.3). The maximum thickness of Tauranga Group sediments in the mine area is 66m, situated in the paleo valley trending NW-SE across the mine extension area.

2.2.4.1 Whangamarino Formation:

Within the Weavers Opencast Mine the Whangamarino Formation is a wholly fluviatile sequence. At the base of the sequence , and unconformably overlying the Te Kuiti group rocks, is a basal conglomerate. In the northeast batters of the 1986-1987 highwall the conglomerate is exposed over a length of 120m, reaching a thickness of up to 8m. It is a compact sequence of predominantly greywacke gravels contained in a finer matrix of interbedded pumice and quartzose muddy sands. In the central and southwestern parts of the highwall the basal conglomerate consists of lenses of gravelly sandy silts and gravelly

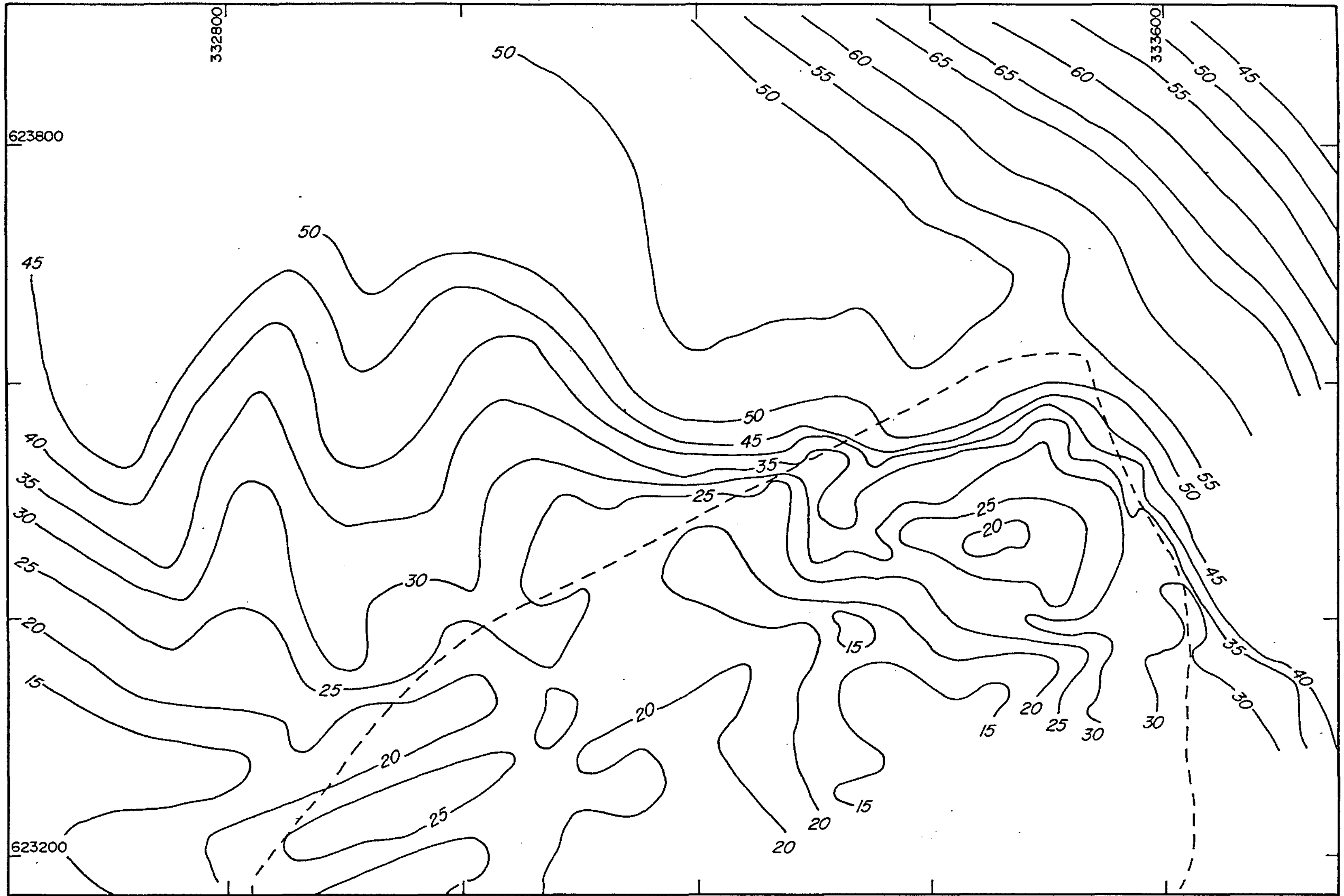


Figure 2·3 Tauranga Group Isopach Map
(after Henderson 1983)

1:1,584 Original Scale

—20— Contour Lines (m thick)
– – – – Edge of Batters, July 1986

muds that range in thickness from 0 to 2m over distances of up to 20m. In the SW sector where the Whangamarino Formation overlies the Glen Afton Claystone a high percentage of marine Tertiary clasts are incorporated into the basal conglomerate. Clast sizes fine upwards from 10cm to 1cm or less and become increasingly mixed with varying proportions of greywacke clasts and fluviatile clayey silts.

Fining upwards from this basal conglomerate is a sequence of stiff light bluish green slightly sandy clayey silts with discontinuous lenses of clay and peat (Figure 2.4). The unit has a maximum thickness of 20m in the northeastern batter slopes, but decreases to 10m in the centre and southwest of the highwall against a paleo "high" in Tertiary rocks. The upper part of the Whangamarino Formation consists of a 2-5m thick, slightly to moderately weathered, stiff, light orange brown clayey silt with plant rootlets and iron oxide staining. This unit in turn grades upwards into a highly to completely weathered organic rich dark brown silty clay (paleo soil).

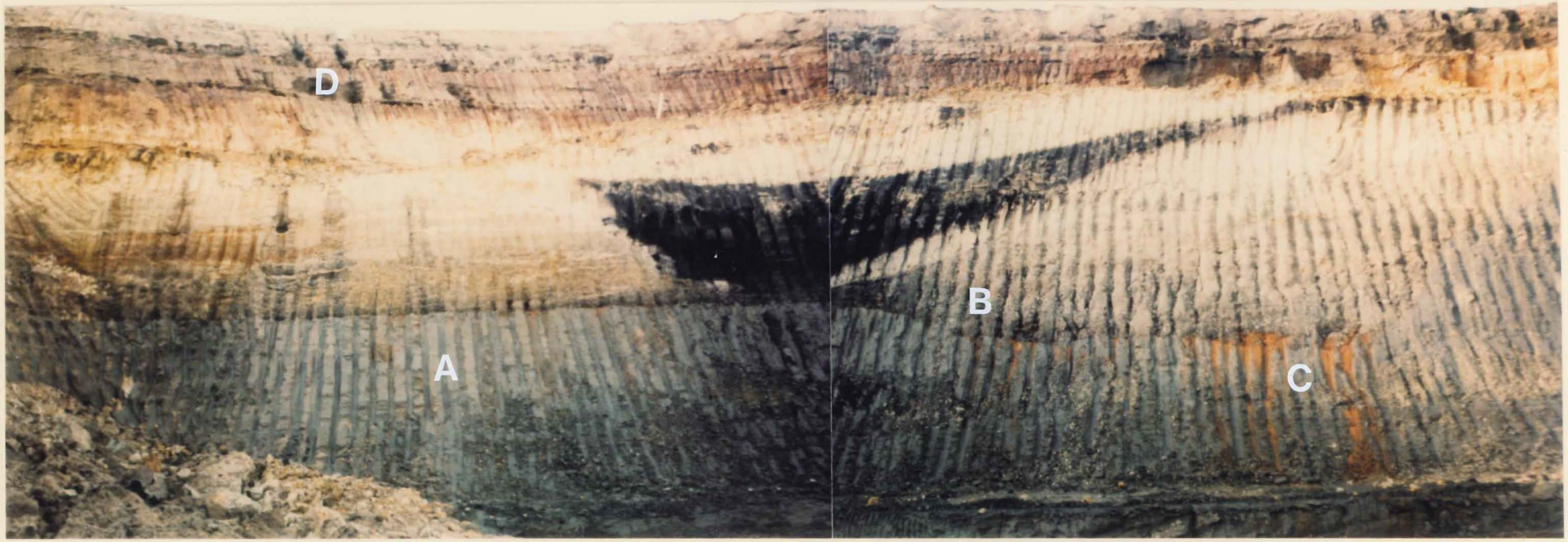
Incised into the silty clays of the Whangamarino Formation are gravelly sand and sandy silt lenses (Figures 2.5 and 2.6) . These occur extensively in the northeastern batter slopes where they are thought to indicate evidence of significant stream incision into the upper Whangamarino Formation during the degradational period that followed the units deposition (Kear & Schofield 1978). Similar channel structures were observed in the Whangamarino Formation in the southwestern batter slopes, immediately above the June 1986 batter failure (section 4.2.2.5).

2.2.4.2 <u>Kauroa and Hamilton Ash Deposits</u>:

The Kauroa and Hamilton ash deposit consists of ignimbritic pale reddish yellow and yellow brown sandy silts and silty clays. The unit has been described in detail by Ward (1967), and was recognized by Kelsey (1986) to mantle the low hills around Huntly.

Within the mine area the Kauroa and Hamilton ash deposits are restricted in their distribution to the eastern mine batter. The units are identified on the basis of their stratigraphic position and colouration, and unconformably overlie the Whangamarino Formation attaining a maximum thickness in the batter face of up to 5m. The units thin rapidly northwards in the batter face and are truncated in the northeast corner of the highwall by the overlying Hinuera Formation.

Figure 2.4: Top of Whangamarino Formation exposed in batter slopes of central highwall (G.R. 332245mE 623470mN) viewing north.



<u>Figure 2.5</u>: Paleochannel incised into Whangamarino Formation clayey silts, (G.R. 333520mE 623580mN) viewing east.
A: stiff clayey silts of Whangamarino Formation;
B: gravelly sand lens grading up into sandy silt;
C: iron staining at base of channel indicating water seepage;
D: piping failures in Hinuera Formation.

Figure 2.6: Paleochannel incisions into Whangamarino Formation, (G.R.333465mE 623575mN) viewing north.

2.2.4.3 Hinuera Formation:

The Hinuera Formation consists of fluviatile pumice rich gravels, sands, silts and clays. The unit increases from 5m in the northeast to a maximum of 10m in the central highwall, but decreases to 4m or less further to the southwest where it thins against a paleo "high"in the Whangamarino Formation. In the SW sector of the highwall it has been truncated by post depositional erosion and buried by the Taupo Pumice Alluvium.

The dominant lithology (Figure 2.7) consists of loose current bedded, yellowish brown to grayish green, gravelly sands and sandy gravels, fining upwards into medium to fine sand and sandy silts. Alldred (1984a) described the occurrence of three clay layers in the Hinuera Formation that stand out in the batter face. The upper clay layer is 0.2-0.6m thick and marks the boundary with overlying Taupo Pumice Alluvium, it is situated at a constant R.L. of +5m and consists of light blue grey, wet, highly plastic, very fine silty clay. A second identical clay layer is situated at +3m R.L. and a third can be identified at the base of the Hinuera Formation (-1m to -3m R.L.) where it unconformably overlies the Whangamarino Formation. The clay bands are continuous over the length of the batter face until but are eroded from the sequence in the southwest of the mine area. (Cross Section Figure 1 Map Pocket)

2.2.4.4 Taupo Pumice Alluvium:

The Taupo Pumice Alluvium is 3m thick at the northeast end of the mine highwall, and thickens up to 5m southwestwards along the batter slopes.

The unit has two sub members (Kear & Schofield 1978), (Figure 2.8), i) a lower member, of fluviatile, loose, creamy white, highly pumiceous quartzose, silt, sand, and gravel layers, interbedded with numerous charcoal fragments, up to 4m thick, with large scale foreset bedding: and ii) an upper member consisting of loose, creamy white, highly pumiceous, quartzose silty sands and gravelly sands, interbedded with charcoal fragments, it is up to 2m thick with current bedding on a scale of 10-20cm. In the northeast and central mine areas the Taupo Pumice Alluvium overlies the Hinuera Formation. In the southwestern part of the mine area the Hinuera Formation has been removed by erosion and the Taupo Pumice Alluvium unconformably overlies the Whangamarino Formation.

Figure 2.7: Hinuera Formation loose pumiceous current bedded gravelly sands. Lens cap for scale (50mm).

Figure 2.8: Taupo Pumice Alluvium; illustrating large scale (2m) current bedding. (G.R. 332950mE 623380mN) viewing north.

2.2.4.5 Undifferentiated Piako Subgroup Sediments:

Overlying the Taupo Pumice Alluvium over the whole of the mine extension area is a 1-2m thick deposit of organic rich clayey silts, silty clays and sandy muds, containing numerous buried logs, tree stumps and reed growths.

2.3 STRUCTURE

2.3.1 Major Faults:

The structure of Tertiary and basement rocks in the mine extension area is dominated by a NE-SW striking fault which sub parallels the orientation of the mine highwall (Figure 1 Map Pocket). The fault plane dips towards 330° at an angle of 65±10°. Fault displacement is normal and varies from 10m in the NE to 20m in the SW of the mine extension area. The horizontal distance between the fault and the 1986-1987 highwall is approximately 60m in the NE to 180m in the SW of the mine area.

A second fault striking NNW-SSE is inferred on the basis of borehole information. The fault plane dips towards 050°at a dip angle of 60°±10°. Fault displacement is normal and varies between 15-20m. North-westwards the fault extends under Lake Wahi while south-eastwards it is assumed to truncate against the NE-SW striking fault.

The faults extend through both the Te Kuiti and basement rocks but are concealed by Tauranga Group overburden and have no surface expression.

2.3.2 Data Collection:

Data was obtained from defect surveys within the Waikato Coal Measures, Glen Afton Claystone and Whangamarino Formation exposed in the mine highwall. Newcastle Group rocks were not exposed and discussion of their structure is based on existing information. Data was collected from the Waikato Coal Measures at two different time periods. The first defect survey was made in February 1986 in mudstone lithologies 4-5m above the Renown seam. Defects were oriented parallel to the highwall (NE-SW) which was situated approximately 40m SE of its July 1987 position. Measurement from NE facing batters were also made as well as from carbonaceous mudstones between the coal seams where these were exposed in trenches.

A second defect survey in coal measure strata was made by Hyde (S.C.M Geomechanics Section) in late 1986. Measurements were made along the highwall. Unfortunately this data is limited as the position of the defect surveys and field descriptions were not available. This data is therefore discussed purely in terms of its orientation.

Defect surveys in Glen Afton Claystone were made in July 1986 in the southwestern sectors of the highwall between (332900mE - 623200mN) and (333060mE - 623340mN) along the base of the Glen Afton Claystone batter, and in July 1987 measurements were taken between 332875mE - 623190mN) and (332820mE - 623340mN) in a drain SW of the large wedge failure in Glen Afton Claystone. The position of the Glen Afton Claystone batter remained unchanged between July 1986 - July 1987 and both data sets are therefore combined.

Defect surveys in Tauranga Group were made in July 1987 and concentrated on the stiff clayey silts of the Whangamarino Formation. The location of these are indicated by the symbols A - D (Figure 2 Map Pocket).

The terminology suggested by Bell and Pettinga (1984) for rock and soil mass descriptions was used to describe defect types in the field. Data is presented in Figures 2.9 to 2.11 as contoured stereographic plots of poles to defects within each of the three units. Defect orientations are presented in terms of dip direction and dip angle. Stereographic plots of raw data are presented in Figures A1.1 - A1.3. Table 2.2 summarises the main defect orientations and joint sets obtained from each set of data, while Figure 2.12 provides a statistical summary of the dip directions and the dip angles measured.

2.3.3 Newcastle Group:

Structure in the basement rocks of the mine area is poorly defined due to lack of exposure. However observations of artificial exposures from road cuts (Kear and Schofield 1978) suggest that the Hakarimata Formation rocks are highly jointed over their entire thickness. This is confirmed in the mine area by Hue (1985) who observed intensely sheared and jointed basement rocks during the preparation of the foundation materials for construction of the No.8 Bund.

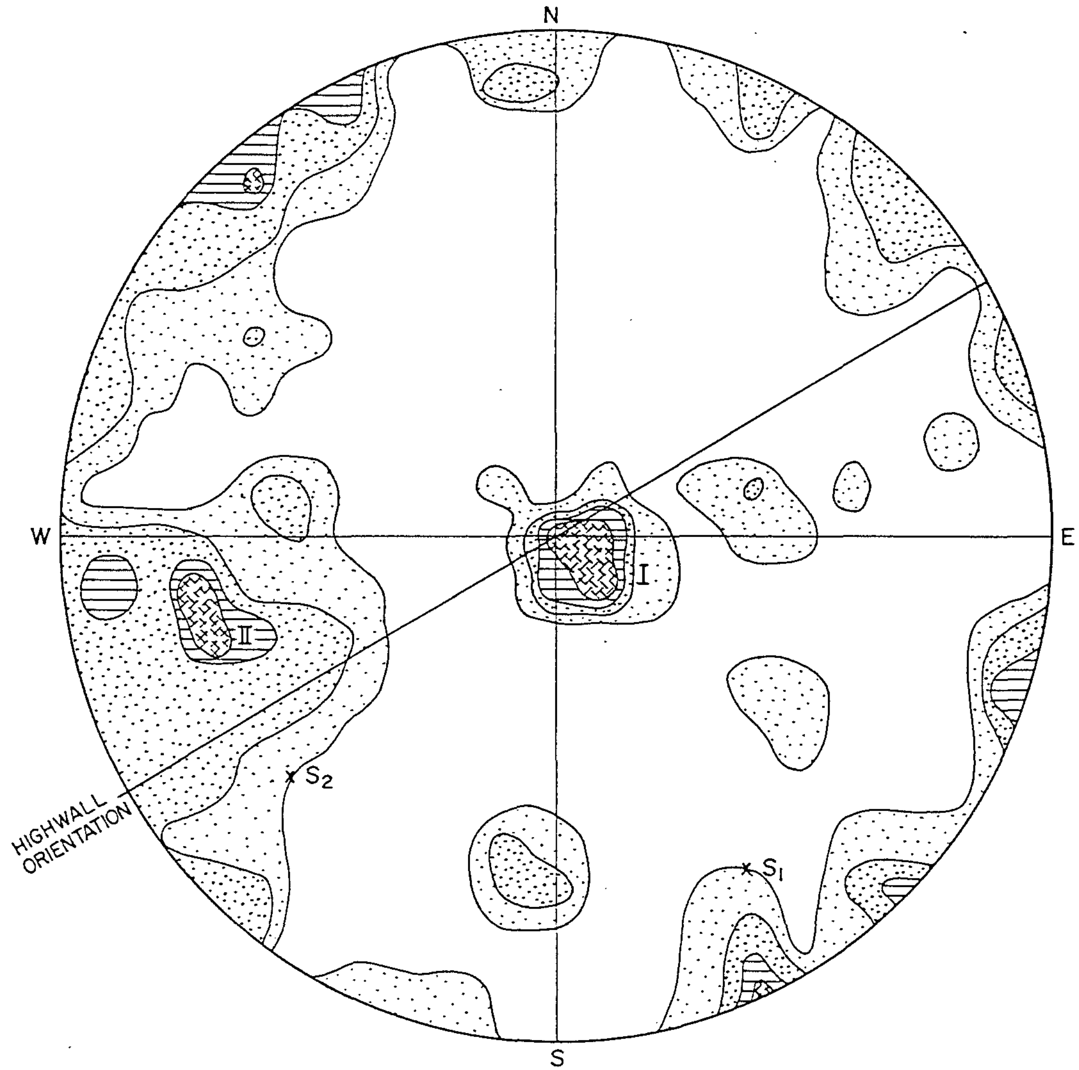
2.3.4 Waikato Coal Measures.

The contoured stereographic plots of poles to defects (Figure 2.9) illustrates data collected for the first defect survey (February 1986), from which a number of points can be concluded;

Table 2.2 Summary of defect orientations.

UNIT	SET	DIP DIRECTION/DIP ANGLE IN DEGREE	PERCENTAGE LEVEL	DEFECT TYPE	REMARKS
	I	000/10	>4		February 1986
W.C.M					N=145
	II	074/60	>4		
	A	150/50	7-10		
	G	230/40	2-5		
W.C.M.	B	256/50	2-5		Hyde 1986 data
	C	055/35	2-5		N=110
	H	268/70	2-5		
	F	000/10	2-5		
	A	150/55	7-10		
	B	230/50	5-7		
	C	060/50	5-7		
g.A.C	D	080/50	5-7		July
	E	250/50	2-5		1986-1987
	F	040/10	2-5		N=110
	X	sub horizontal	5-7		
Tga.Gp.	Y	160/90	5-7		July 1987
	Z	330/90	12-14		N=170
					Major Faults in
	S_1	330/65			Mine extension
	S_2	050/60			area

All angles are in $\pm$ 10°



Percentage concentration of poles to defects

- 0-1%
- 1-2%
- 2-3%
- 3-4%
- > 4%

NOTES:

1. Rock defects have been plotted on a Schmidt equal area net, lower hemisphere stereographic projection.
2. Joints are shown as a contoured stereographic projection based on the poles of 145 defects.
3. Contours are based on the number of poles within each 1% unit area of the projection.
4. Orientation of defects are expressed as α/β (dip direction/dip angle)

S_1, S_2 = poles to major faults

Figure 2.9 : Stereographic plot of rock defects, Waikato Coal Measures (Te Kuiti Group) N = 145 Highwall Weavers Opencast Mine, Huntly, Waikato Region (Feb. 1986)

i) Figure 2.9 illustrates no clear pattern of defect orientations. Two defect sets can be identified which only reach up to the 4% level of concentration. Defect set I are poles to bedding and bedding plane shears which dip north at 10-15°. Defect set II correspond to the pole of a minor fault (2m displacement) with a set of genetically related closely spaced (0.1-0.2m) joints up to 1m on either side.

ii) the orientation of minor faults measured is quite variable and do not correlate with the orientation of the major faults (Figure A1.1)

iii) sub vertical joints illustrate significant variability in their orientations and generally do not rise above the 2-3% level, with slightly higher concentrations for joints parallel to the highwall.

The data collected by Hyde 1986 in Waikato Coal Measure strata is illustrated in (Figure 2.10), and illustrates the following points:

i) A principal concentration of poles corresponding to defects oriented 150°±10°/50°±10° (set A) occurs which strike sub parallel to, and dip out of the highwall. This defect set also strikes parallel to the major NW-SE trending fault (S_1) in the extension area. A conjugate to this set appears to be present (set G) with an orientation of 330°±10°/40°±10°. This set is likely to be under represented in the survey data due to its orientation with respect to the highwall.

ii) A second conjugate set of defects (sets B and C) can be identified at the 2-5% level with orientations of 055°±10°/55°10° and 268°±10°/50°±10° at right angles to the strike of the highwall and subparallel the NNW-SSE striking fault (S_2).

iii) a defect set (H) with an orientation corresponding to 256°±10°/70°±10° can also be identified.

iv) Defect set F is assumed to correspond to bedding attitudes, which have an orientation of 000°±10°/ 10°±5° respectively, and remains unchanged from bedding orientations measured in the first survey.

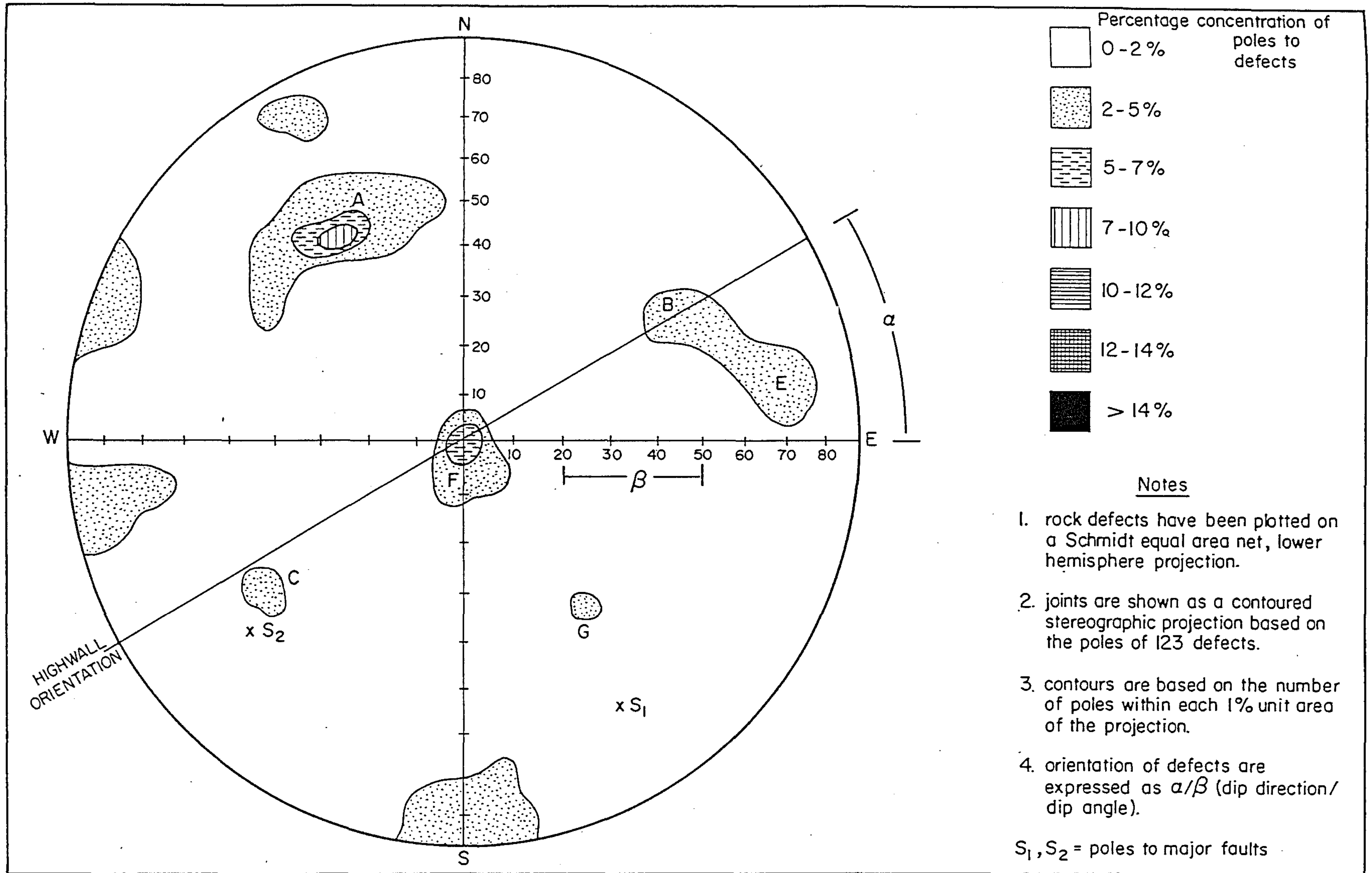


Figure 2·10 Stereographic Plot of Rock Defects - Waikato Coal Measures (Te Kuiti Group), N = 123, Highwall Weavers Opencast Mine, Huntly, Waikato Coal Region (July 1986 - July 1987) (based on data collected by Mr K. Hyde for State Coal)

2.3.5 Glen Afton Claystone:

The contoured stereographic plot (Figure 2.11) illustrates well defined sets of defect orientations from which the following conclusions can be drawn;

i) Defect set A (150°±10°/55°±10°) reaches up to the 7-10% level of concentration , and corresponds to joints striking subparallel to, and dipping out of the highwall. Defects belonging to the conjugate of this set were (G) observed and measured, but remain below the 2% level of concentration.

ii) Defect sets B and C represent a conjugate fault set observed in the field corresponding to orientations of 230°±10°/50°±10° and 060°±10°/50°±10° respectively which correspond to the expected orientation of defect sets parallel and conjugate to the major fault 060°±10°/60°±10° in the mine extension area. Defects of sets B and C strike at 80°-90° to the highwall, where they intersect with joints of defect set A.

iii) Defect sets D and E form a conjugate set with orientations of 080°±10°/50°±10° and 250°±10°/50°±10° respectively, striking at 50°-70° to the orientation with the highwall, where they intersect with joints of defect set A.

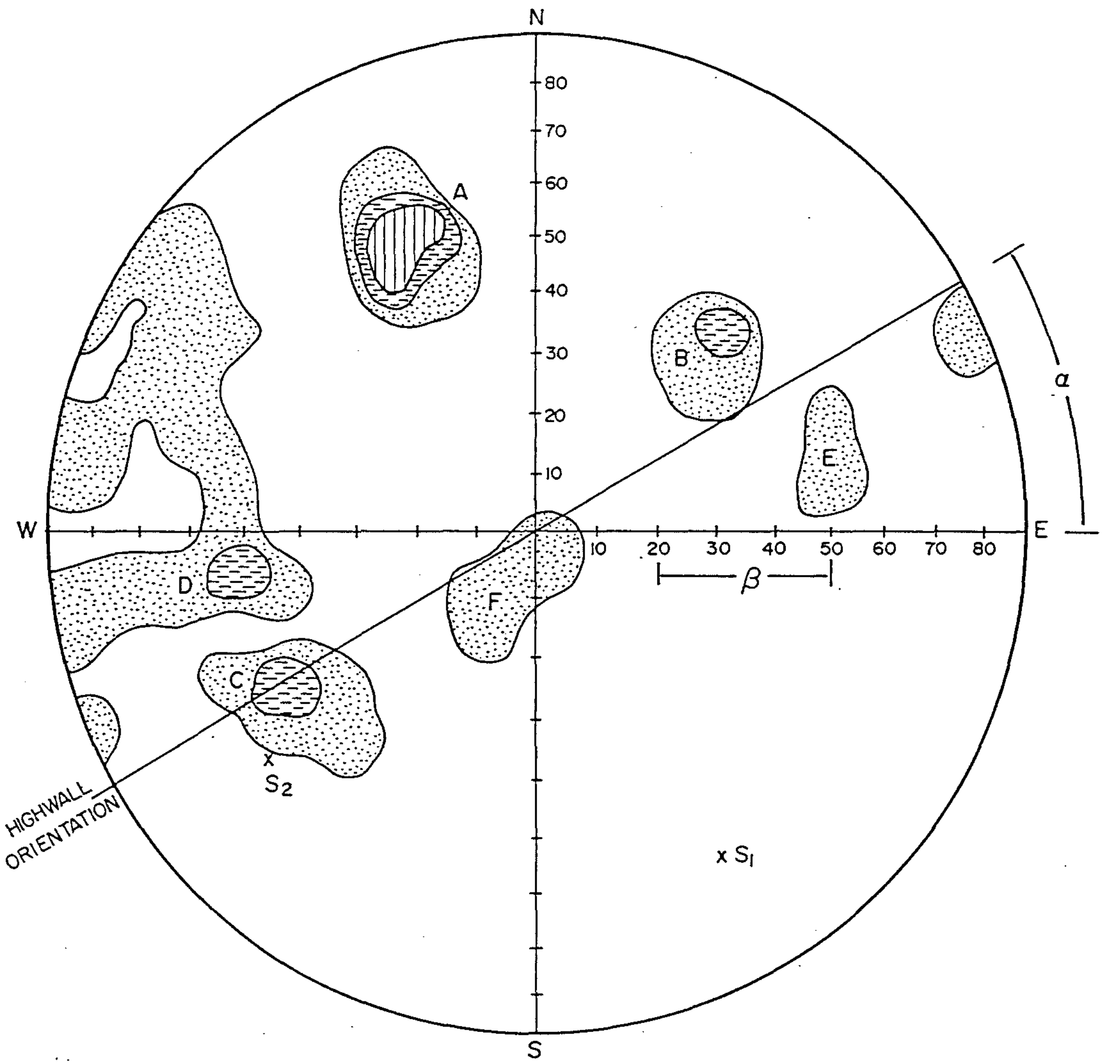
iv) Defect set F illustrates bedding attitudes (as determined from mm. thick laminations) as well as sub horizontal shears. Bedding is oriented at 020°±20°/ 10°±5°.

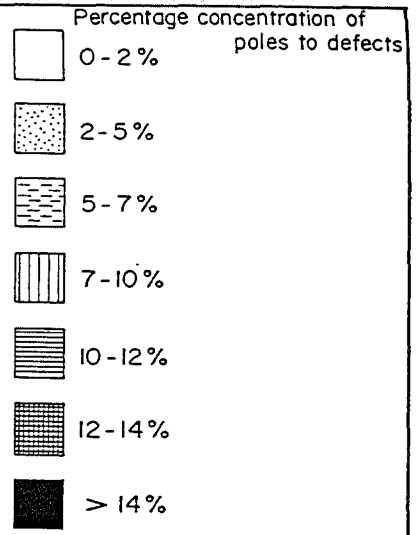
v) sub vertical joints are present and produce a scattered distribution of poles at the 2-5% level of concentration in the NW quadrant of the stereographic plot.

2.3.6 Interpretation of Defect Data in Tertiary Rocks:

i) Bedding attitudes in the Waikato Coal Measures and Glen Afton Claystone strata are similar, and suggest that the Tertiary rocks are dipping to the N and NE at 10°-15° into the highwall.

ii) The data collected suggests that the Tertiary rocks posses at least two structural domains, between the north and south of the mine area. The boundary between these two domains lies between the February 1986 and July 1986 positions of the high wall. The presence of different





Notes

1. rock defects have been plotted on a Schmidt equal area net, lower hemisphere projection.
2. joints are shown as a contoured stereographic projection based on the poles of 110 defects.
3. contours are based on the number of poles within each 1% unit area of the projection.
4. orientation of defects are expressed as α/β (dip direction/ dip angle.

S_1, S_2 = poles to major faults

Figure 2.11 Stereographic Plot of Rock Defects - Glen Afton Claystone (Te Kuiti Group), N = 110, Highwall Weavers Opencast Mine, Huntly, Waikato Coal Region (July 1986 - July 1987)

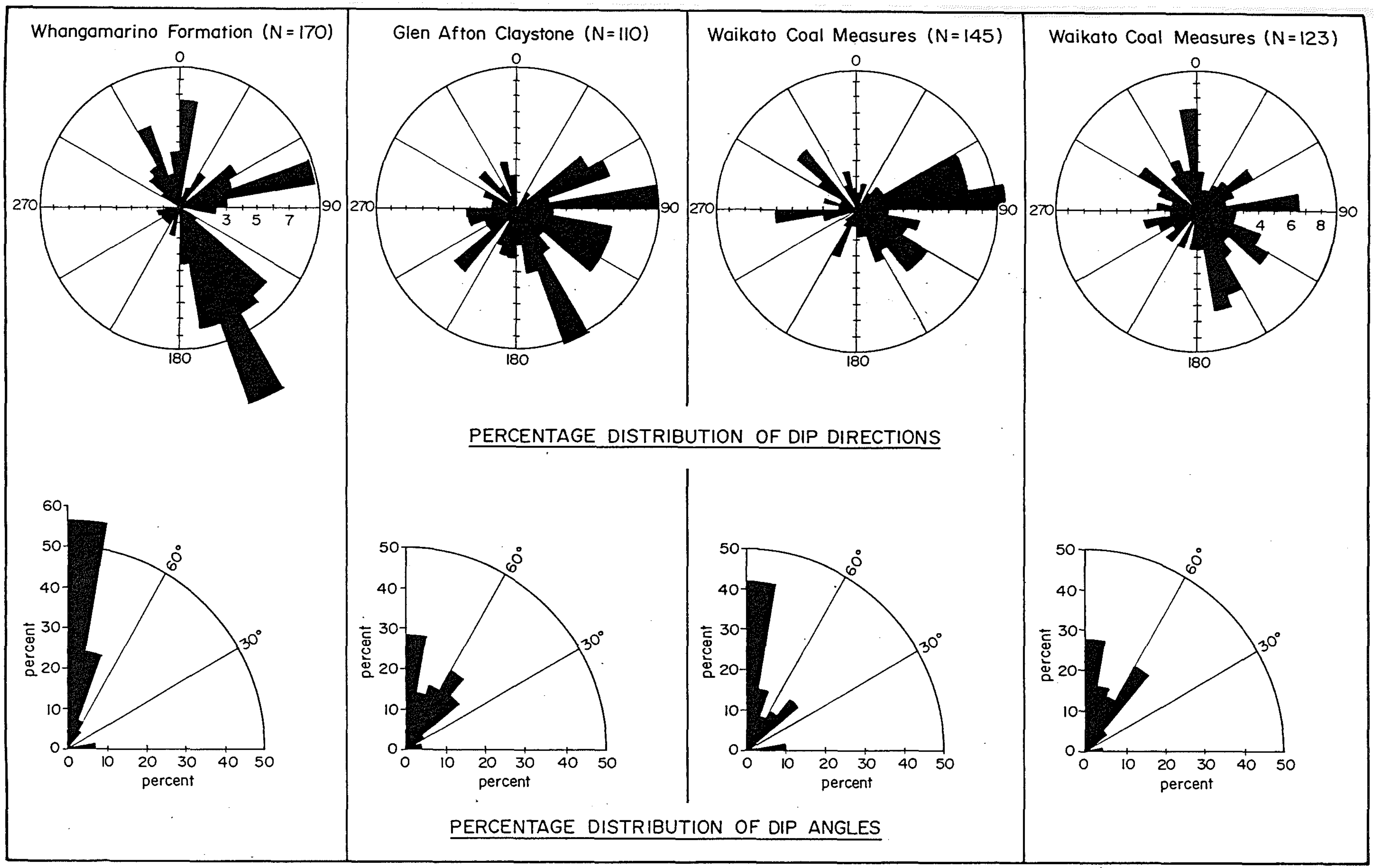


Figure 2.12 Rosette Diagrams of Dip Directions and Dip Angles in Tertiary and Quaternary Strata, Weavers Opencast Mine (Huntly), Waikato Coal Region (July 1986 - July 1987)

structural domains is suggested by the lack of well defined defect orientations in data collected in Coal Measure strata during February 1986, which contrasts with the better defined defect sets observed in both Waikato Coal Measure and Glen Afton Claystone formations between July 1986 and July 1987.

iii) Both Waikato Coal Measure strata and Glen Afton Claystone possess defects striking subparallel to, and dipping out of the batter face, which intersect with joints of other defect sets.

iv) The fact that the defect sets A and G, and B and C, parallel the orientation of the major faults in the mine extension area suggests that these stuctures are related. At the present time there is insufficient data to strongly support this conclusion. However if a relationship exists between defect orientations in the highwall and the orientation of the major faults, it will become better defined as the highwall advance continues to the northwest, due to more regular spacing and greater persistence of defects with these orientations.

v) Sub-vertical joints in all three data sets are variable in their orientation and do not produce significant levels of concentration. A possibility exists that a number of vertical joints measured in the Tertiary strata are blast induced. Contemporaneous joints resulting from shrinkage and compaction (Penseler 1930) may also be present near the base of the W.C.M but these are less likely to exist in the upper strata of the coal measure sequence or the Glen Afton Claystone.

2.3.7 Field Descriptions of Defects in Tertiary Rocks.

2.3.7.1 Bedding:

In the Waikato Coal Measure strata contacts between mudstone lithologies are often gradational over a few millimetres and show no apparent discontinuities.

The Glen Afton Claystone is massive and bedding is not recognised in the mine.

2.3.7.2 Joints:

Joints in coal measure strata and Glen Afton Claystone vary in continuity from less than 0.5m up to 5 or 6m. Typical joints are planar to slightly curved in appearance, and are often truncated at their ends by other defects. Joint surfaces are generally clean, smooth to slightly rough with an aperture size ranging between 0.1mm up to 5mm, rare 10mm. Joints with an aperture size in excess of 1mm may be infilled with clay materials.

2.3.7.3 Minor Faults:

Glen Afton Claystone and coal measure strata exposed in the highwall contain numerous faults with throws of between 2-5m. Fault displacement is typically normal. Fault traces can often be recognised by their persistence ranging between 10-15m across the batter face. Fault apertures may be tight but more commonly are infilled by (mm to cm thick) gouge layers, consisting of crushed claystone lozenges in a weathered clay matrix. Slickensides can be observed on the surfaces of some but not all faults. Defect spacing between fault sets varies from less than 1m where conjugate faults intersect, up to 20m to the next defect set.

2.3.7.4 Shear Zones:

Thin (mm. thick) layers of clayey shear gouge were observed in the bedded coal measure strata at the base of concretionary layers and coal seams, and less frequently along bedding planes in the mud and claystone lithologies. Shear zones are persistent and can be traced over 20-30m along the batter face. Stereonet data shows most are dipping into the batter face parallel to bedding. Shear zones most often occur in the proximity of minor faults, and are assumed to develop when fault displacement is taken up along bedding planes. The morphology of shear layers within and at the base of coal seams has been described previously by Sinclair (1986) who referred to them as bedding parallel shears.

Engineering geological mapping identified the presence of weak highly persistent clay layers in the Glen Afton Claystone 2-3m above its contact with the Waikato Coal Measure succession. Two such shear zones were observed, the first (Figure 2.13), dips into the batter face at 10°, sub parallel to bedding of the underlying Te Kuiti Group sequence, and can be traced over 40m along the batter beyond which it

Figure 2.13: Weak highly persistent (40m+) clay layer in Glen Afton Claystone. G.R. 333015mE 623330mN, viewing east 3m above contact with Waikato Coal Measures. Dip is c.10 into batter face.

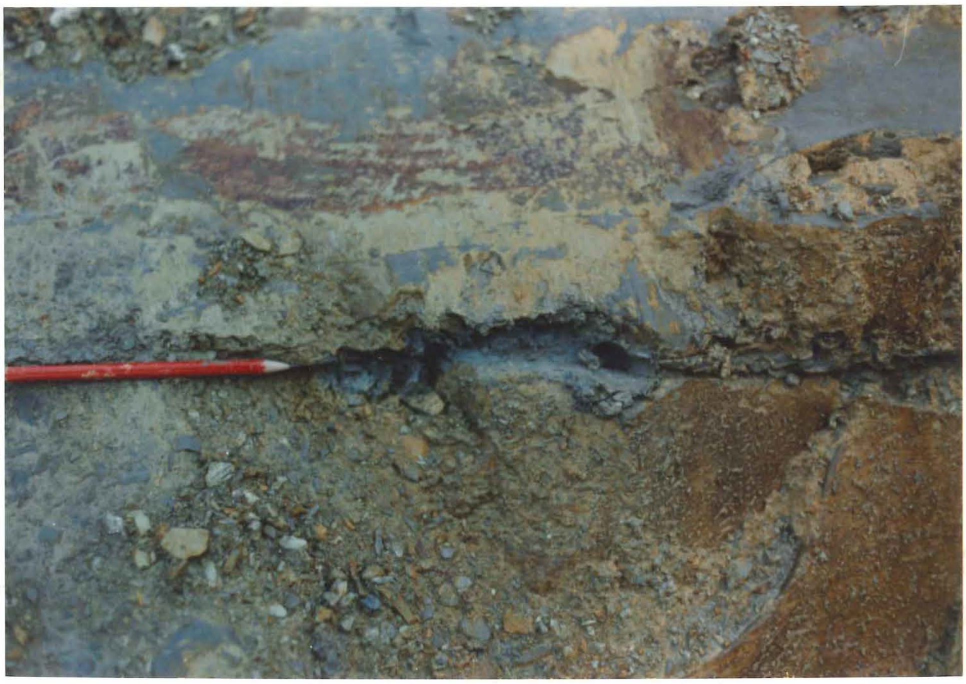


Figure 2.14: Close up view of shear gouge clay, referred to in Fig. 2.13, Clay is 1-5mm thick, highly weathered with lozenges of Glen Afton Claystone in the matrix.

is obscured by debris. Clay material infilling the aperture varies between 1-5mm in thickness (Figure 2.14) and consists of discoloured blue grey, highly weathered, moist slightly silty clay.

A second shear zone clay layer was mapped at approximately the same stratigraphic level in the southwestern most batter slopes (Hegan pers. comm. 1987) (Figure 2.15) The dip orientation of the shear zone is into the face, and can be traced over a distance of 15m before being obscured. The shear zone gouge has a thickness up to 1cm and consists of moderately to highly weathered, yellowish brown to grey green, damp, highly sheared silty clay , containing pebble size clasts of unweathered, coherent Glen Afton Claystone material.

The presence of bedding plane shears in Glen Afton Claystone has been described previously by Hue (1983) who recognised these as a major factor in highwall instability at the Waipuna, Smiths, and MacDonalds Opencast mines of the Rotowaro Coal Field (Figure 1.1).

2.3.8 Tauranga Group:

Figure (2.16) shows a contoured stereographic plot of 170 poles to bedding and jointing in the stiff clayey silt unit of the Whangamarino Formation.

2.3.8.1 Bedding:

Bedding orientations (set X) are sub horizontal with dips ranging from 0°-5°. Bedding plane defects are spaced at intervals of 0.2-1.0m and are distinctive because of their highly oxidised reddish brown appearance, (Figure 2.17). Bedding is highly continuous and can be traced along the batter face in excess of 30m. Surface asperities are up to 3mm high with a wavelength of 8-10cm, (Figure 2.18).

2.3.8.2 Joints:

Two sub vertical joint sets are identified; joint set, (defect set Z), strikes 060°-240° parallel to the highwall orientation parallel to the highwall orientation (Figure 2.19). Dip angles are $90^\circ \pm 5^\circ$ towards 330° and 150°. The second joint set (Y) strikes 160°-340°, almost at right angles to the highwall. Dip angles are sub vertical towards 070° and 250° respectively. Joints are continuous over the thickness of the unit and have a spacing of between 0.5-2m. Aperatures are tight but joint surfaces are commonly oxidised. Joint surfaces show asperities of 2-3mm in height with wavelengths of several centimetres.

Figure 2.15: Shear gouge clay layer in Glen Afton Claystone, wetern batter slope 3m above contact with Waikato Coal Measures. (G.R. 332850mE 623135mN) viewing west.

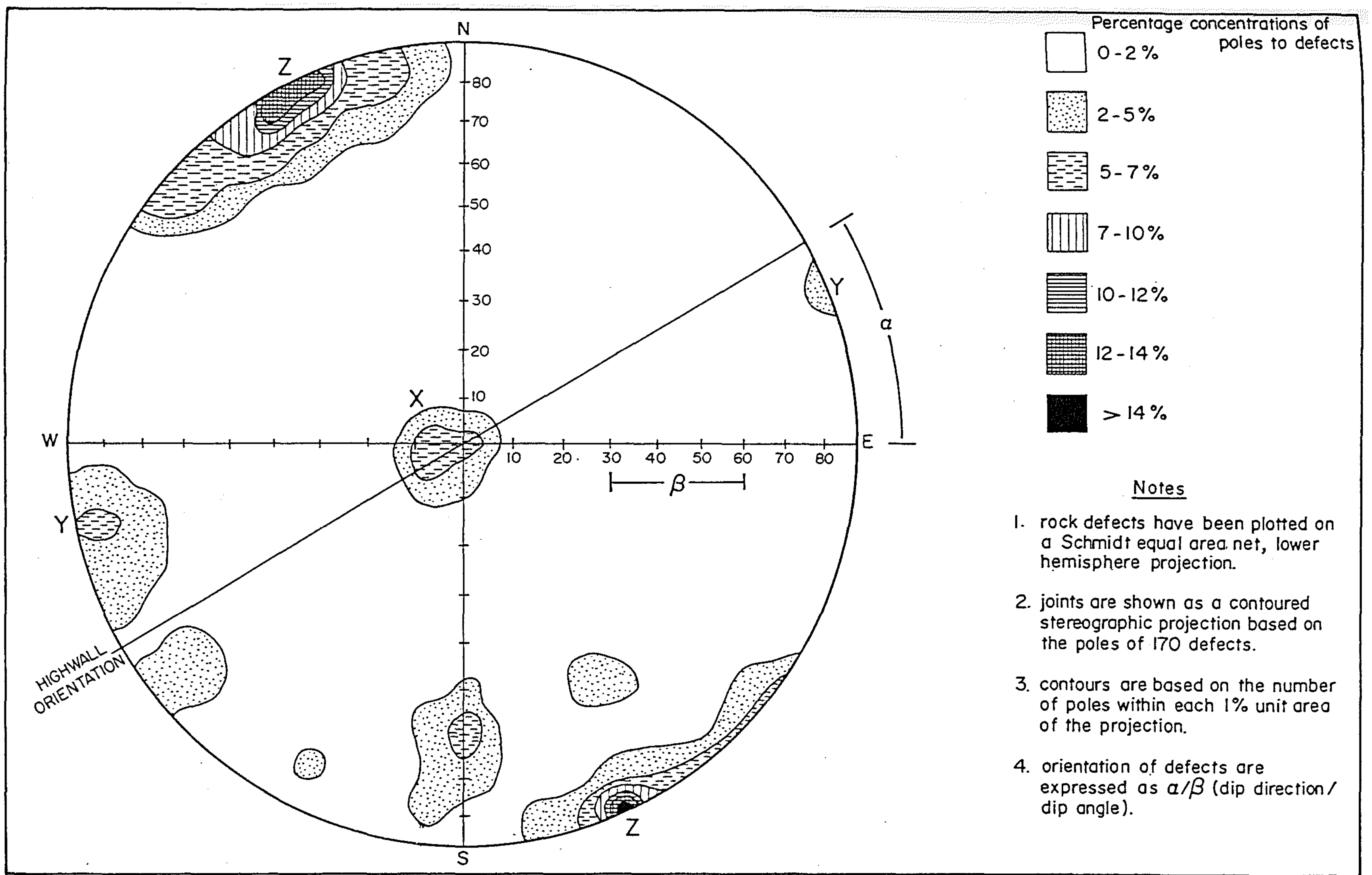


Figure 2·16 Stereographic Plot of Rock Defects - Whangamarino Formation, (Tauranga Group), N = 170, Highwall Weavers Opencast Mine, Huntly, Waikato Coal Region (July 1986 - July 1987)

Figure 2.17: Plan view of bedding plane surface in a block sample collected from the Whangamarino Formation, illustrating oxidised appearance of bedding plane defects. The surface asperities present across the surface are up to 3mm high.

Figure 2.18: Cross sectional view of bedding plane surface in block sample (Fig. 2.17), illustrating amplitude of waviness along the bedding plane surface.

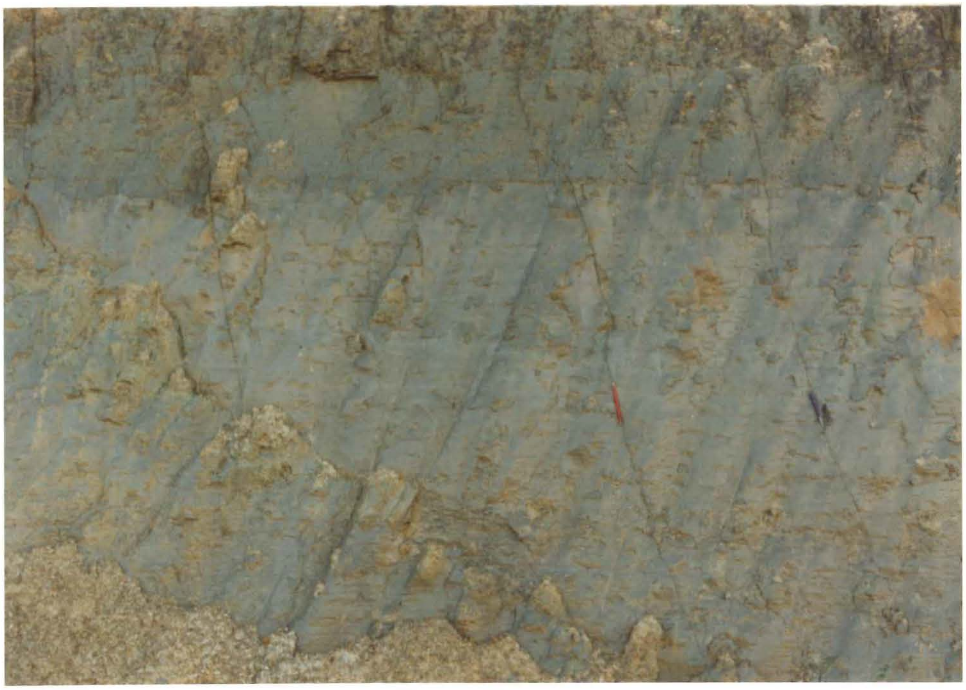


Figure 2.19: Sub vertical joint set in Whangamarino Formation clayey silts striking parallel to highwall, as observed in eastern batter slopes. (G.R. 333560mE 623550mN) viewing east.

On a scale of several metres joints vary from planar to slightly wavy.

2.3.9 Comparison of Te-Kuiti and Tauranga Group Data:

Stereographic analysis of defect data suggests that Te-Kuiti and Tauranga Group rocks form two separate structural domains, which are separated by the Te-Kuiti-Tauranga Group unconformity contact. Te-Kuiti Group rocks show a high proportion of continuous inclined defects (40°-60°) which subparallel the orientation of the major faults in the mine extension area. A genetic relationship between rock mass defects in Tertiary strata and the major faults can be assumed but this requires further verification with the advance of the highwall.

Sub vertical joints in the Tauranga Group strata are regularly spaced and continuous and form two clearly defined defect sets.

2.4 HYDROGEOLOGY

2.4.1 Hydrogeological Units:

Within the present Weavers Opencast Mine and its extension area the Tauranga Group succession contains three aquifer On the basis of piezometric data (section 2.4.2) the Taupo Pumice Alluvium and the Hinuera Formation form two distinct aquifer units. However because of their close stratigraphic relationship, and the fact that the clay layer separating these two units is lensic and is not present in the SW sector of the mine area, they are referred to collectively as the 'Upper Aquifer'. The silts, sands and gravels at the base of the Whangamarino Formation forms the Lower Aquifer unit. On the basis of falling head permeability tests, Hue (1985) estimated the material permeabilities for both aquifers to range between 10^{-5} to 10^{-6} m/sec.

The clayey silts of the upper Whangamarino Formation have an estimated permeability of 10^{-9}m/sec. (Frederickson 1985) and forms an aquitard separating the Upper and Lower Aquifers. However field observations indicate the aquitard has variable thickness and imperviousness, and leakage through the aquitard is evident particularly around those areas where channel deposits have been incised into the unit.

Te Kuiti and Newcastle Group rocks underlying the Tauranga Group sequence act as aquicludes with material permeabilities estimated at 10^{-10}m/sec. (Frederickson 1985). However rock mass defects, particularly bedding and jointing can produce high secondary permeabilities. Hue (1985) records that during the construction of No.8

Bund, water flows of 0.4 l/sec. were obtained from shattered basement rocks. Table 2.3 summarizes the hydrogeological units and their properties.

2.4.2 Aquifer Distribution and Piezometric Surfaces:

The Upper Aquifer is present over the entire mine extension area, where it reaches a maximum thickness of 15m. Distribution does not extend under Lake Wahi (Hue 1985). State Coal Mines have monitored piezometric levels in the Upper Aquifer since 1983. On the basis of this information Hue (1985) concludes that the Taupo Pumice Alluvium is an unconfined aquifer with rainfall as the main source of recharge. The piezometric surface lies between 2-3m below the ground surface and fluctuates with daily and seasonal variations in precipitation.

The Hinuera Formation is regarded as a semi confined aquifer. Piezometric levels are consistently less than for the Taupo Pumice Alluvium and range between 7.5m and 2.5m R.L.. A review of piezometric data (Geo Engineering 1985) indicates that only some of the piezometers installed in the Hinuera Formation display seasonal fluctuations in piezometric levels suggesting that the vertical permeability between the Taupo Pumice Alluvium and the Hinuera Formation is variable between locations.

A high impediment to vertical groundwater movement is inferred where the piezometric head in the Hinuera Formation do not correspond with fluctuations in the piezometric head of the Taupo Pumice Alluvium, whilst a low impediment to groundwater movement is assumed where the piezometric head in both aquifer units fluctuate with each other. Vertical permeability is assumed to be dependent on the extent and thickness of the clay layers in the Hinuera Formation.

The distribution of the Lower Aquifer with respect to the present opencast mine is illustrated in (Figure 2.20). The unit strikes east-west across the mine area and extends underneath Lake Wahi. Unit thickness varies from 0-35m. According to Hue (1985) the Lower Aquifer is semi confined and the piezometric surface shows slight seasonal fluctuations in phase with Lake Wahi and the Upper Aquifer.

The piezometric surface varies between -4m R.L. at the lake edge to -13m R.L. at the mine highwall. (Hue & Delahunty 1986). Drawdown centres on 5 horizontal drains that have been installed since 1983. The piezometric surface has a gradient of 1:150 (V:H ratio) up to a distance of 1000m from Weavers Opencast Mine, which steepens to 1:10

TABLE 2.3 HYDROGEOLOGICAL UNITS

Unit	Thickness	Designation	Description	coeff perm. (ms^{-1})
Lake bed Muds	0-15m	aquitard	lightly compacted organic rich, clayey silts, silty clays and sandy muds.	-
Taupo Pumice Alluvium	3-5m	unconfined aquifer	pumice rich, loose, silty fine, medium to coarse sand and gravel.	10^{-5}-10^{-6}
Hinuera Fm	0-10m	semi confined aquifer	pumice rich, loose sandy silts and silty sands with continuous layers of silty clay.	10^{-5}-10^{-6}
Upper Whangamarino Fm	10-20m	aquitard	clayey wilts with discontinuous bands of peat and wedge shaped lenses of sandy silt and silty sand.	10^{-9}
Lower Whangamarino Fm	0-35m	(semi confined aquifer)	Highly compacted, pumice rich greywacke rich, gravelly sandy muds and muddy gravels.	10^{-5}-10^{-6}
Glen Afton Claystone Waikato Coal Measures		aquiclude	weak to moderately weak indurated, mudstone, siltstone and sandstone.	10^{-10}
Hakarimata Formation		aquiclude	indurated siltstone and sandstone.	10^{-10}

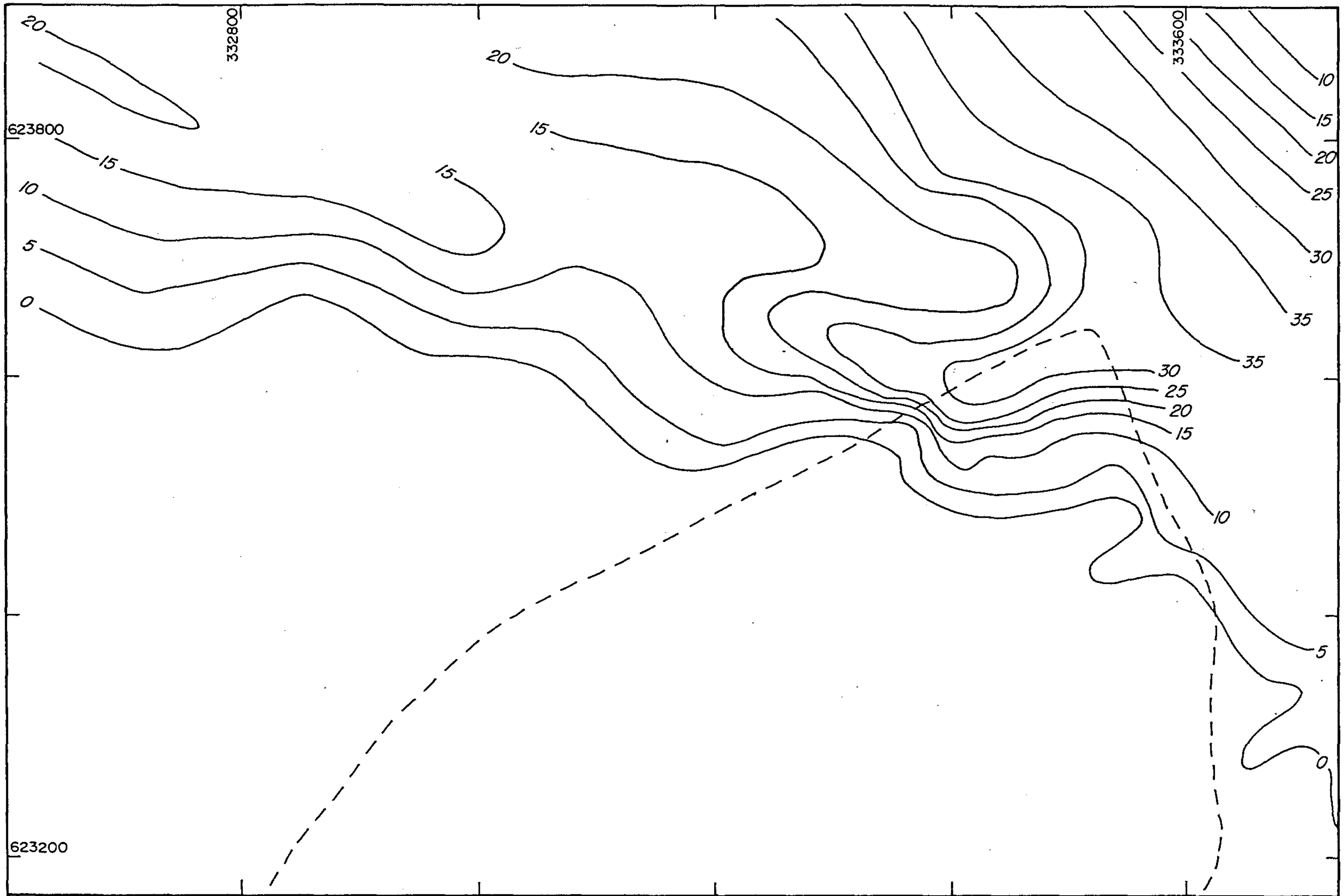


Figure 2·20 Lower Aquifer Isopach Map (after Henderson 1983)

1:1,584 Original Scale

—20— Contour Lines (m thick)
– – – Edge of Batters, July 1986

within 100m of the mine face.

2.4.3 Hydraulic Connections:

Hue (1985) suggests that there is no evidence for a hydraulic connection between Lake Wahi and the Upper Aquifer. Piezometric data suggests that lake level fluctuations influence the water table up to a distance of 200m beyond the lake's shores. Beyond this distance water table fluctuations reflect primarily daily and seasonal fluctuations in precipitation. Significant drawdown occurs only within 30m of the mine face where the hydraulic gradient steepens from sub horizontal to 1:10 (V:H ratio).

Lower Aquifer piezometric levels are in phase with variations in the level of lake Wahi and the Upper Aquifer. Hue (1985) postulates a hydraulic connection between Lake Wahi and the Lower Aquifer, with recharge occurring as a result of seepage through the lake bed muds. A connection with the Upper Aquifer also exists as a result of leakage through the clayey silts of the Upper Whangamarino Formation. Leakage is likely to have intensified as a result of the installation of the horizontal drains.

2.4.4 Water Discharge:

The principal sources of water discharge into the mine at the current time are

i) Drainage of water from the Upper and Lower Aquifer units (Figures 2.21 and 2.22) The area of batter slopes over which the Upper Aquifer was exposed during the research period is approximately 6400m^2 (800m long by 8m thick) and for the Lower Aquifer is 960m^2 (120m long by 8m thick). Hue & Delahunty (1986) have measured water inflow from the aquifer by gravity drainage into the pit as 10 l/sec. and 2 l/sec. respectively.

ii) Surface runoff from precipitation.

2.5 SYNTHESIS

Figure (2.23) provides a tentative engineering geological site model for batter stability in Weavers Opencast Mine. Potential factors contributing to batter instability are summarised in this model, and include;

Figure 2.21:
Groundwater discharge into the pit at the base of the Hinuera Formation where it overlies a low permeability clay layer, 2 days after a period of heavy rainfall.

Figure 2.22:
Groundwater discharge into the pit from the Lower Aquifer. The puddle at the base of the batter formed in 20 seconds. Also observe the compact nature of the greywacke gravels and pumiceous sands and silts exposed in the face.

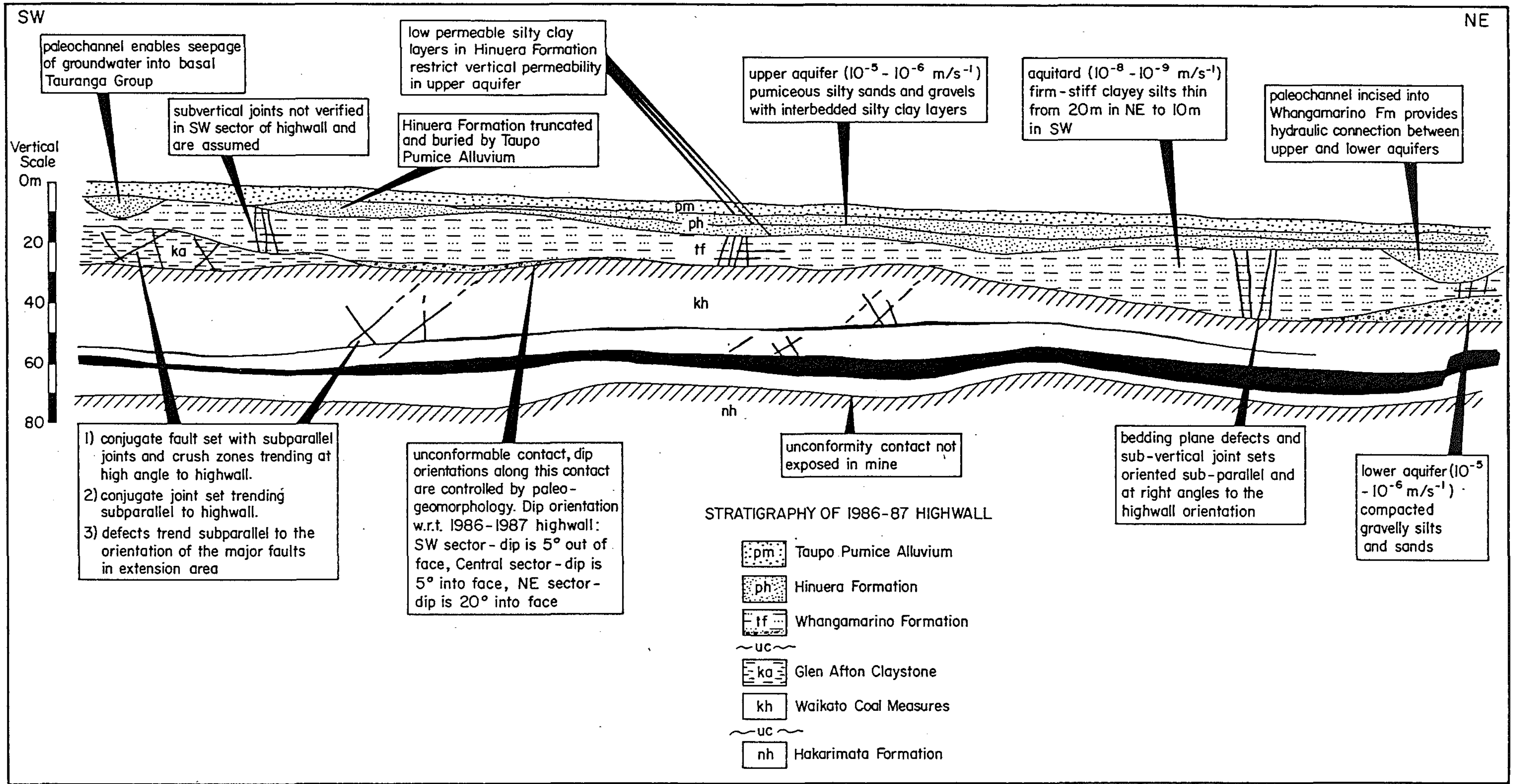


Figure 2.23 Tentative Engineering Geological Model

1) <u>Rock Material and Soil Material Factors</u>:

a) <u>Rock Material</u>: The Tertiary sequence of the mine extension area consists of a 40-45m thick succession of Waikato Coal Measure strata, conformably overlain by an up to 25m thick succession of Glen Afton Claystone, Pukemiro Sandstone, and Mangakotuku Siltstone. Both coal measure and Tertiary marine strata show a high susceptibility to slaking in response to wetting and drying.

b) <u>Soil Material</u>: Unconformably overlying Tertiary rocks is a 15-30m thick Tauranga Group sequence consisting of the Whangamarino Formation, the Kauroa and Hamilton Ash deposits, Hinuera Formation and Taupo Pumice Alluvium. Within this sequence it is possible to distinguish soils with distinctive engineering properties; the Whangamarino Formation and Kauroa and Hamilton Ash deposits are consolidated fine grained cohesive soils, while the Taupo Pumice Alluvium and Hinuera Formation are poorly consolidated low cohesive granular soils which are susceptible to disaggregation in water.

2) <u>Rock Mass and Soil Mass Factors</u>:

a) <u>Rock Mass Defects</u>: In the Te Kuiti Group rock defects striking subparallel, and at right angles to the highwall are present. Those which are significant to highwall stability include:

i) Defect set A a conjugate joint set which strikes subparallel to the highwall and dips out of the batter face;

ii) Defect sets B and C, and defect sets D and E formed by conjugate faults and joints which strike at a high angle to the batter face and intersect with defect set A;

iii) Low angle shear zones are recognised in both Glen Afton Claystone and Waikato Coal Measure strata but these dip into the batter face.

b) <u>Soil Mass Defects</u>: Persistent joint and bedding planes occur in the stiff silty clays of the Whangamarino Formation and include:

i) two sub vertical joint sets (Z and Y) striking subparallel and at right angles to the highwall respectively;

ii) a sub horizontal bedding plane defect set (X).

c) <u>Rock Mass and Soil Mass Contact:</u> Field observations show:

i) Glen Afton Claystone and Waikato Coal Measure strata underlying the unconformable contact with the Tauranga Group are highly weathered and show loss of strength and discolouration; and

ii) in the SW sector of the mine the unconformity surface has an unfavourable dip orientation with respect to the highwall and dips out of the batter slope at 5°

3) <u>Hydrogeological Factors</u>:

a) Two aquifer units are present within the Tauranga Group sequence. The Lower Aquifer unit ($k=10^{-5}$to $10^{-6}ms^{-1}$) consists of compacted gravelly muds and sands at the base of the Whangamarino Formation their maximum thickness in the NE of the highwall, where they infill a depression in the unconformity surface.

b) Upper aquifer materials ($k=10^{-5}$ to $^{-6}ms^{-1}$)are formed by loose gravelly sands and silts of the Hinuera Formation and the Taupo Pumice Alluvium. In the NE and central sectors of the highwall the vertical permeability of the Upper aquifer is restricted by the presence of low permeable clay layers in the Hinuera Formation, and the thickness of the Whangamarino Formation clayey silt unit. In the SW sector of the highwall the absence of the low permeable clay layers provide the upper aquifer with a high vertical permeability and enables groundwater infiltration into the underlying Whangamarino Formation to occur.

c) The relatively impermeable ($k=10^{-9}ms^{-1}$) stiff clayey silts of the Upper Whangamarino Formation function as an aquiclude between the Upper and Lower aquifer units. However seepage of groundwater, through this unit into basal Tauranga Group sediments overlying the unconformity surface occurs as a result of; i) a decrease in Whangamarino Formation unit thickness from a maximum thickness of 20m in the NE of the highwall, to 10m in the southwest, ii) the presence of gravelly sand and sandy silt lenses, incised into the unit during post depositional erosion, and iii) increased secondary permeability resulting from the presence of sub vertical joints and sub horizontal bedding.

CHAPTER 3
LABORATORY INVESTIGATIONS

3.1 INTRODUCTION

3.1.1 Laboratory Programme:

Laboratory investigations were conducted to quantify the engineering geological model,(Figure 2.23) of the highwall. The investigations consisted of:

1) Physical characterisation of Tauranga Group materials in terms of their density , void ratio, moisture content, clay mineralogy and particle size characteristics. Material characterisation concentrated on the Whangamarino Formation, although limited testing was also carried out on the overlying Hinuera Formation and Taupo Pumice Alluvium.
2) Shearbox testing of Whangamarino Formation materials to obtain shear strength parameters along the unconformity surface in the SW sector of the highwall, as well as along bedding planes and vertical joints observed in the Whangamarino Formation.

3.1.2 Objectives:

The principal objective of material characterisation is to identify variations in the physical parameters of Tauranga Group materials across the highwall which may be significant with respect to their shear strength characteristics. The Whangamarino Formation is considered to be the most important unit as it directly overlies the unconformity surface, and is likely to be involved in any deep seated failures within the Tauranga Group materials.

A variation in the shear strength of Tauranga Group materials from NE to SW was observed by Alldred (1984b) on the basis of cone penetrometer testing. To account for this he suggested a decrease in the cohesive parameters of the soil resulting from a decrease in clay content across the batter face in this direction.

The objective of shearbox testing is to investigate the potential for shearing along the unconformity surface, and/or the bedding planes as possible planes of failure in basal Tauranga Group materials.

3.2 PHYSICAL CHARACTERISATION OF MATERIALS

3.2.1 Test Procedures and Results:

Sampling of Tauranga Group materials was restricted to batter faces above the bench level at -8.5m R.L. (Figure 1 map Pocket). Collection of samples from the batter face below this bench level by conventional means (rope or ladder), was against mine safety regulations due to its height and steepness (20m at 80°). Cost, as well as the condition of the bench surface prevented the use of a cherry picker.

Laboratory procedures for dry density, solid density, natural moisture content, grainsize analysis and Atterberg Limits are in accordance with NZ Standards 4402 Part 1 (1980). Determination of bulk density, was made following the procedures described in NZS 4402 Part 2P test 21 (1981). Void ratios were determined using the values obtained for dry density and solid density. Clay mineralogy was determined on a Phillips PW 1050 X-Ray Diffractometer using Nickel filtered $CuK\alpha$ radiation. The tube was run at 34kV and 34mA with the divergence slits set at 1°, the receiving slit at 0.2mm, and the anti-scatter slit at 1°. Oriented <2um fraction clay mounted samples were scanned from 2° 2θ to 33° 2θ at a speed of 1° 2θ/min. Clay mounts for qualitative mineral identification were prepared using the dropper on glass method, and allowing the suspension to air dry for 24 hours. Clay mounts were subjected to various treatments to aid in clay mineral identification, these include;

i) saturation of clay mounts with a concentration of 10% glycerol in water to aid in identification of Smectite clays;

ii) saturation of clay mounts with formamide (according to the method of Churchman 1984), to enable distinction of halloysite from kaolinite; iii) boiling of clay suspensions in 10% HCL for 10 minutes and 20 minutes to help distinguish between chlorite and kaolinite;

iv) heating of clay mounts up to temperatures of 350°, 550° and 800° for 1 hour periods, to help distinguish smectite clays, kandite clays and Mg chlorite; and

v) the sodium fluoride reactivity test (NZS 4402 Part 1 test 13) was used to determine allophane content.

Results of material characterisation are summarised in Figures 3.1-3.5 and are discussed in section 3.2.2. Grainsize analyses for selected samples are presented separately in Appendix 2. Atterberg Limit data are summarized in Figure A3.1.

3.2.2 Interpretation and Discussion

3.2.2.1 Void Ratios, moisture contents and densities:

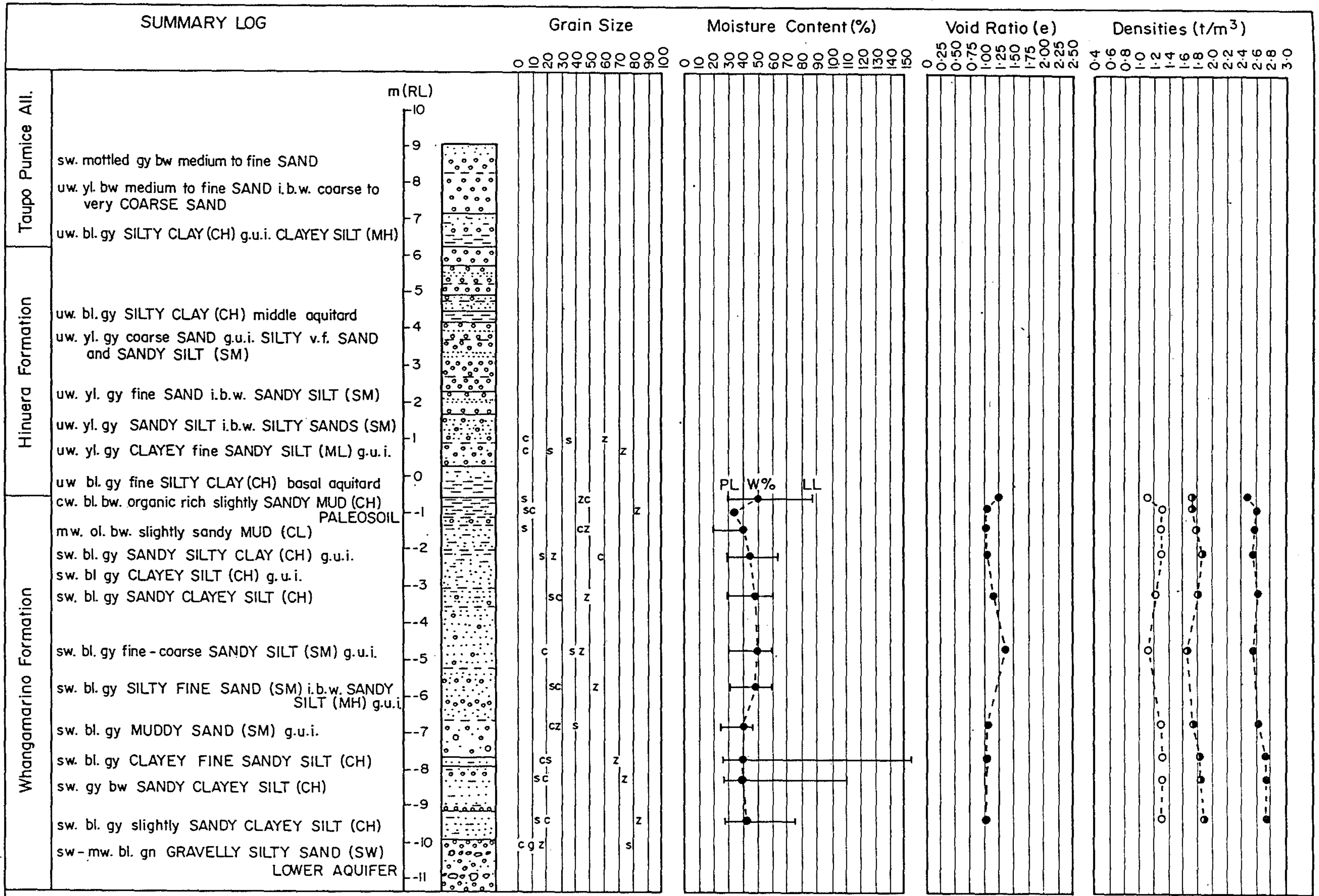
Samples obtained from batter logs 1-5, (Figures 3.1-3.5) are characterised by low dry densities and high void ratios and moisture contents. The average values and standard deviations of these parameters obtained for each face log, are summarised in Table 3.1 . From this it can be seen that the highest void ratios and moisture contents, and lowest dry densities in the Whangamarino Formation are associated with highly organic clays, while significantly higher densities and lower moisture contents and void ratios are associated with Whangamarino Formation clayey silts and sandy silts of low organic content .

Within the clayey and sandy silt materials of the Whangamarino Formation, dry density decreases from an average value of $1.26 tm^{-3}$ in the NE sector of the highwall to $1.0 tm^{-3}$ in the SW sector, while void ratio and moisture content increase from 1.08 to 1.46 and 43% to 56% from NE to SW. It is assumed that this trend in physical properties reflects greater thickness and burial depths of Whangamarino Formation materials in the NE. However this trend needs to be better defined by a more detailed sampling programme, to reduce the large standard deviations obtained as a result of material variability.

The silty clay units of the Hinuera Formation posses very low dry densities, high moisture contents, and high void ratios, which remain almost constant across the batter face.

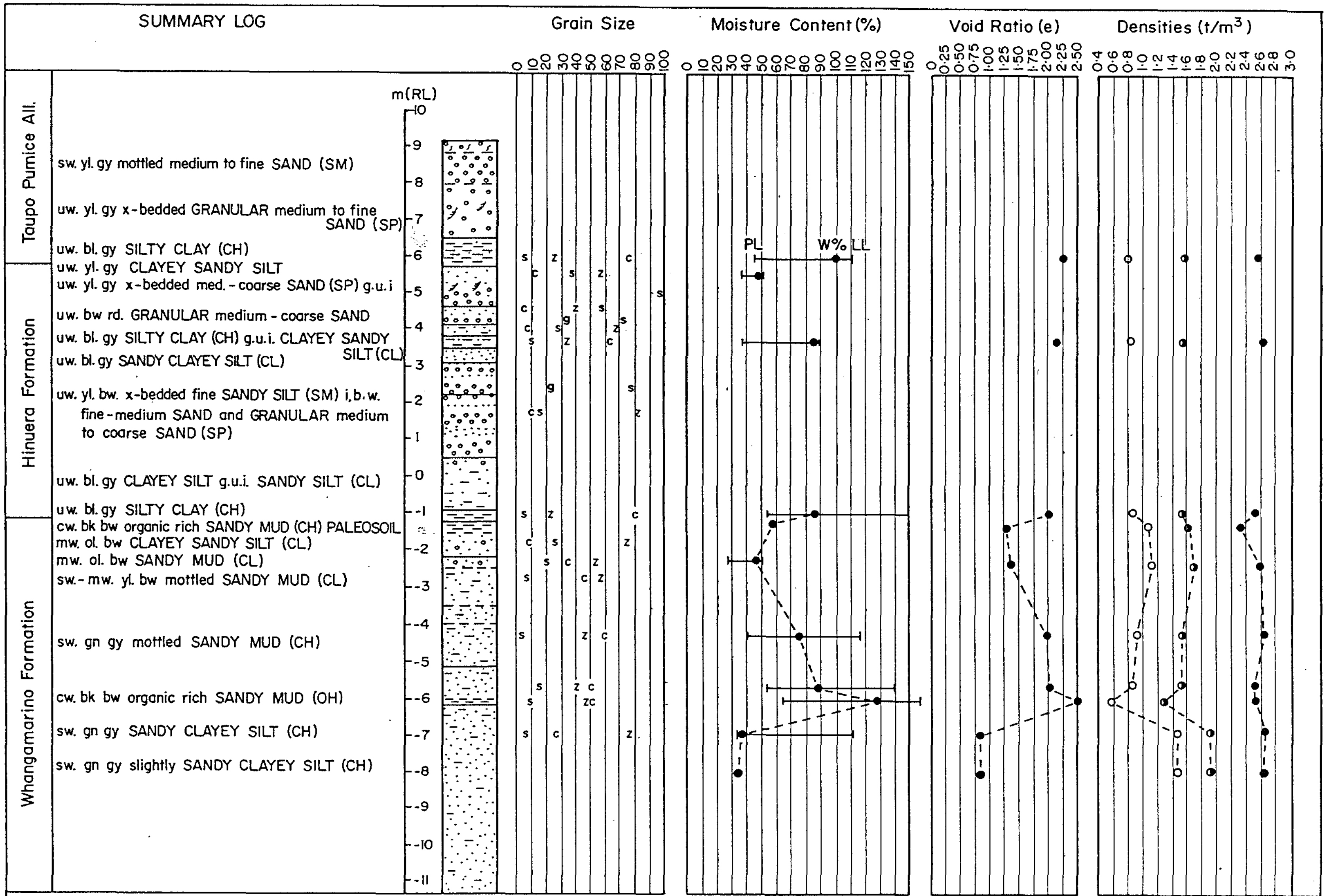
3.2.2.2 Particle Size Distribution:

Taupo Pumice Alluvium and Hinuera formation materials sampled from the batter logs are typically well graded and range from gravelly sands to clayey silts (Figures 3.1-5). Hinuera Formation sands are characterised by fining upward sequences which grade up from granular medium to coarse sands (Figure A2.1) at the base of the sequence, into silty sands and sandy silts (Figure A2.2)). Clay content within these sequences are low (less than 10%) . However silt content in the fining upward sequences may reach up to 70-80% in the sandy silt units.



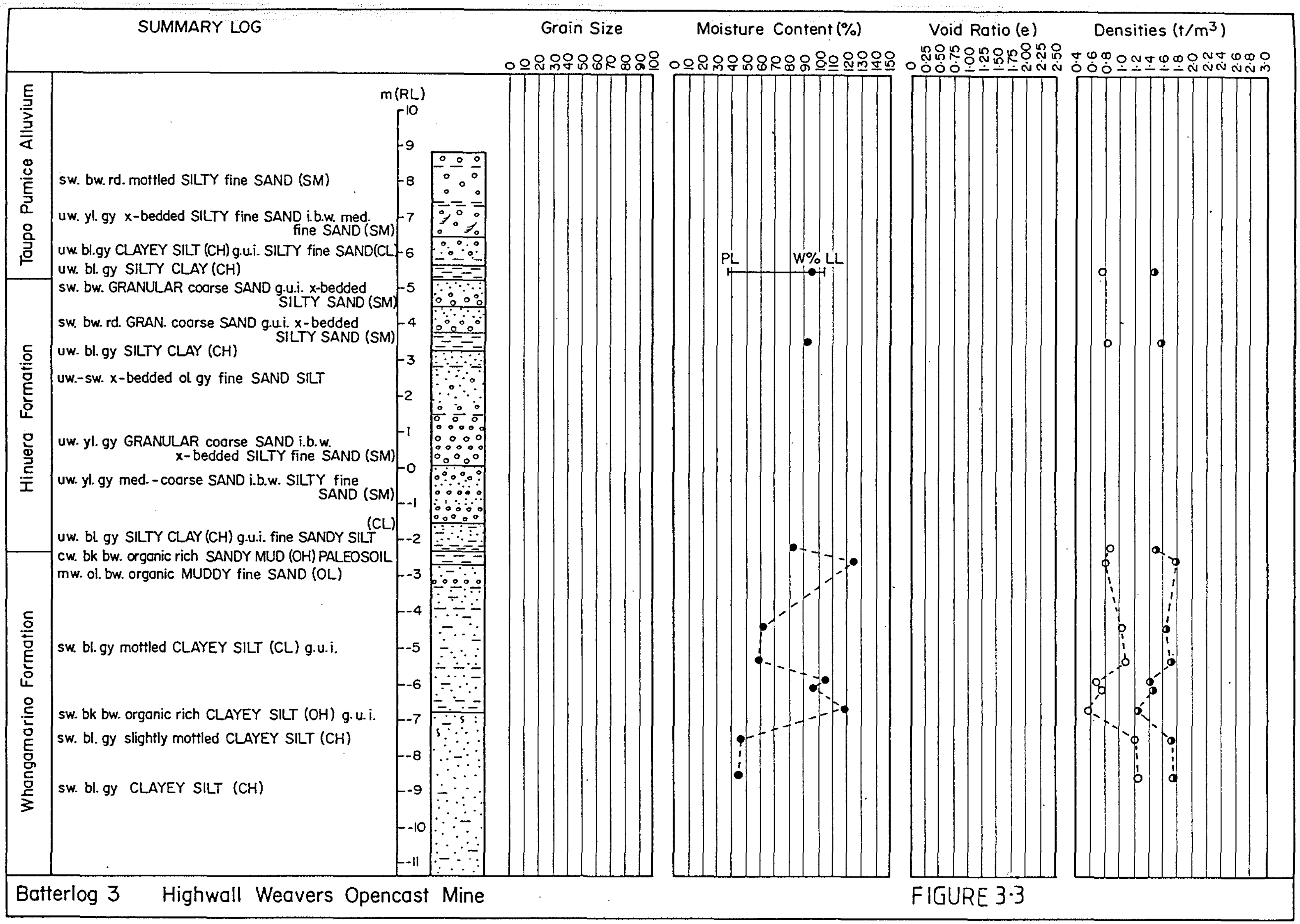
Batterlog I Highwall Weavers Opencast Mine

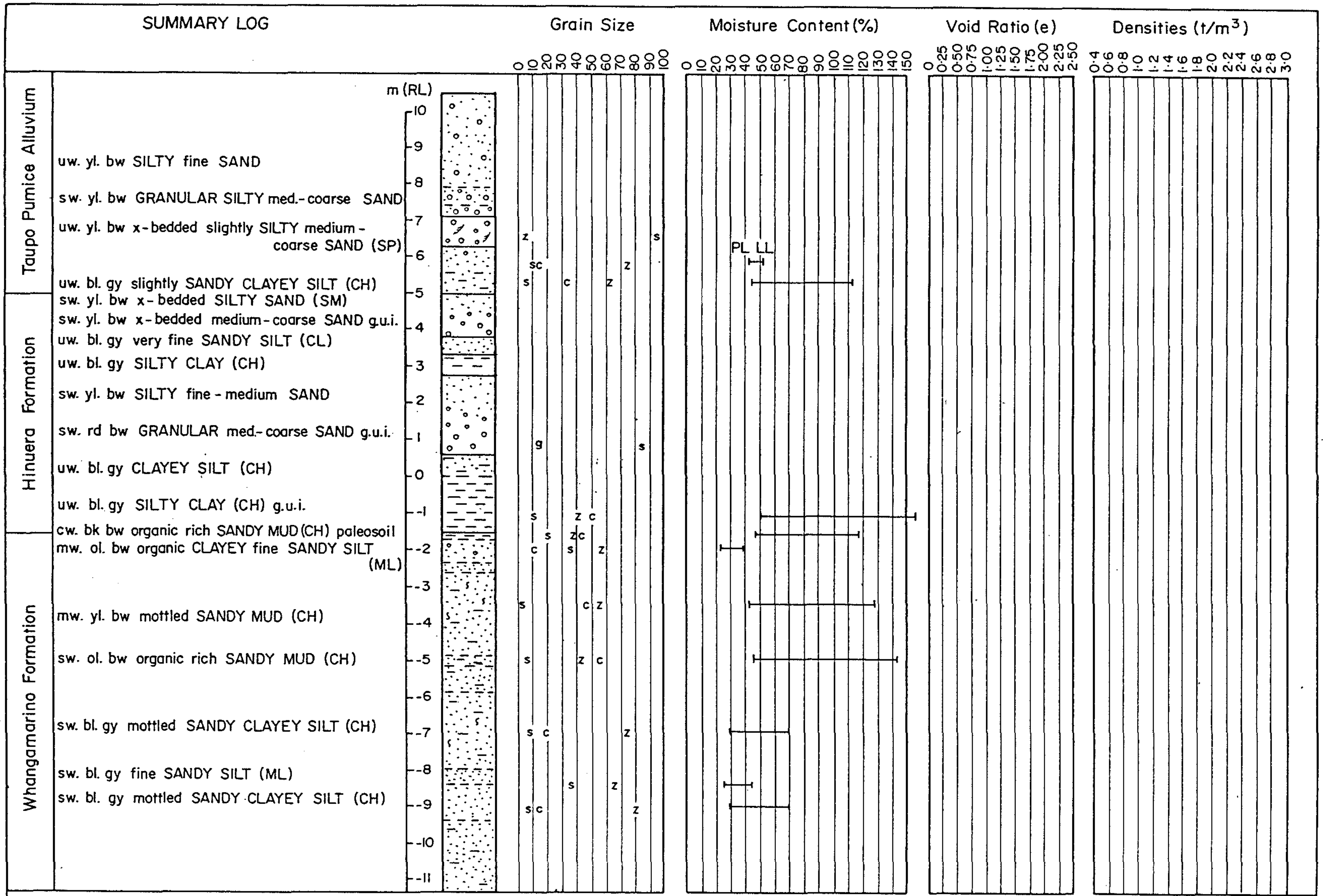
FIGURE 3·1



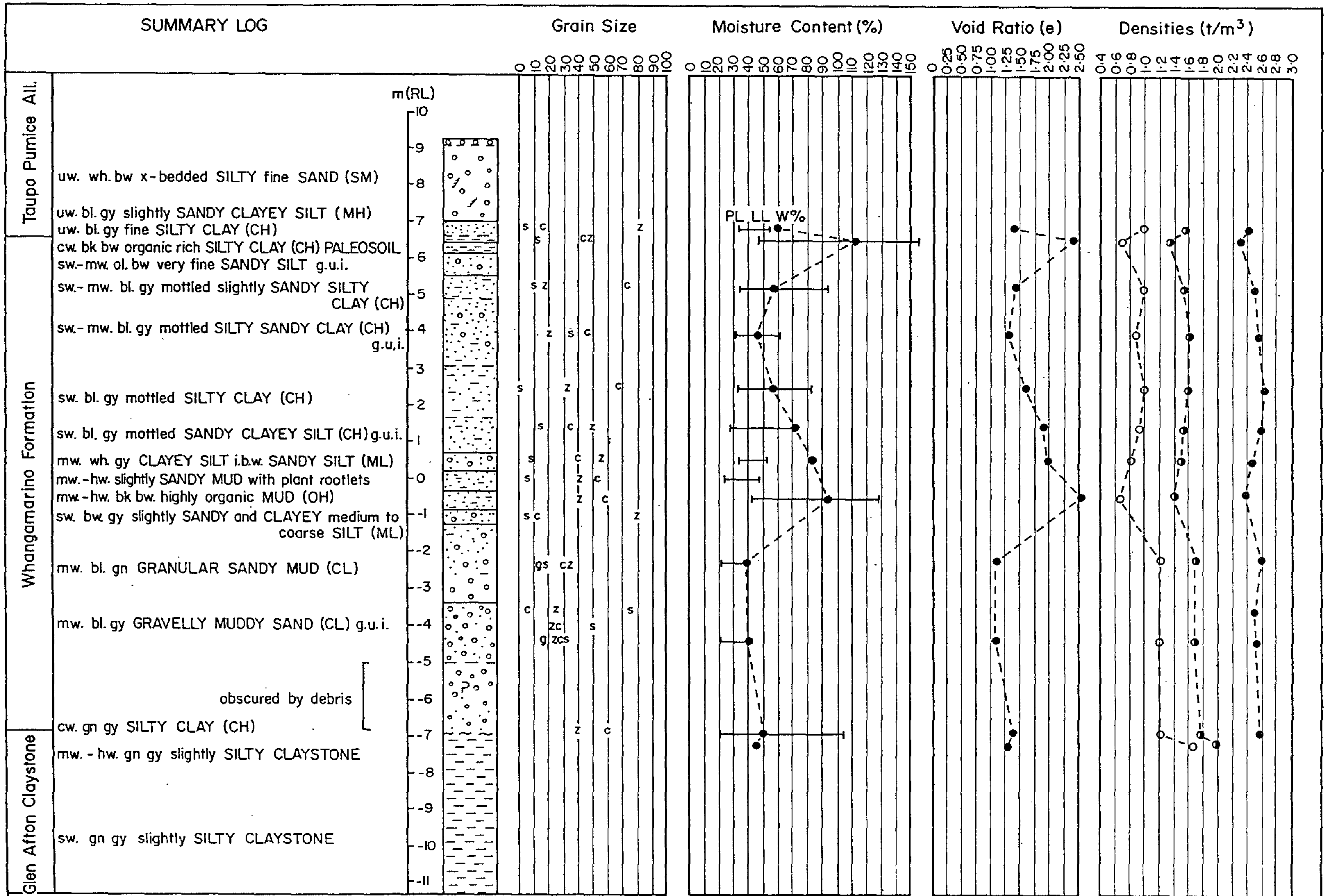
Batterlog 2 Highwall Weavers Opencast Mine

FIGURE 3·2


SUMMARY LOG
Grain Size
Moisture Content (%)
Void Ratio (e)
Densities (t/m³)
Taupo Pumice Alluvium
Hinuera Formation
Whangamarino Formation
m (RL)
sw. bw. rd. mottled SILTY fine SAND (SM)
uw. yl. gy x-bedded SILTY fine SAND i.b.w. med. fine SAND (SM)
uw. bl. gy CLAYEY SILT (CH) g.u.i. SILTY fine SAND (CL)
uw. bl. gy SILTY CLAY (CH)
sw. bw. GRANULAR coarse SAND g.u.i. x-bedded SILTY SAND (SM)
sw. bw. rd. GRAN. coarse SAND g.u.i. x-bedded SILTY SAND (SM)
uw. bl. gy SILTY CLAY (CH)
uw.-sw. x-bedded ol. gy fine SAND SILT
uw. yl. gy GRANULAR coarse SAND i.b.w. x-bedded SILTY fine SAND (SM)
uw. yl. gy med.-coarse SAND i.b.w. SILTY fine SAND (SM)
uw. bl. gy SILTY CLAY (CH) g.u.i. fine SANDY SILT (CL)
cw. bk bw. organic rich SANDY MUD (OH) PALEOSOIL
mw. ol. bw. organic MUDDY fine SAND (OL)
sw. bl. gy mottled CLAYEY SILT (CL) g.u.i.
sw. bk bw. organic rich CLAYEY SILT (OH) g.u.i.
sw. bl. gy slightly mottled CLAYEY SILT (CH)
sw. bl. gy CLAYEY SILT (CH)
PL
W%
LL
Batterlog 3
Highwall Weavers Opencast Mine
FIGURE 3·3



Batterlog 4 Highwall Weavers Opencast Mine FIGURE 3·4



Batterlog 5 Highwall Weavers Opencast Mine

FIGURE 3·5

Table 3.1 AVERAGE DRY DENSITY, VOID RATIO, MOISTURE CONTENT RELATIONSHIPS FROM BATTERLOG 1-5.

		BL 5	BL 4	BL 3	BL 2	BL 1	ALL BATTERLOGS
Whangamarino formation (CL) and (CH) Material	Dry Density (tm^{-3})	1.0	NT	1.1	1.2	1.26	1.15
	Standard Deviation	(0.13)		(0.1)	(0.2)	(0.7)	(0.16)
	Samples Tested	(9)		(4)	(4)	(10)	(27)
	Void Ratio	1.46		NT	1.16	1.08	1.24
	Standard Deviation	(0.34)			(0.45)	(0.1)	(0.33)
	Sample	(9)			(4)	(9)	(22)
	Moisture Content (%)	56		56	52	43	50
	Stendard Daviation	(15)		(7)	(15)	(5)	(12)
	Samples Tested	(9)		(4)	(4)	(10)	(27)
Whangamarino Formation (OH) Material	Dry Density (tm^{-3})	0.7	NT	0.8	0.8	NT	0.8
	Standard Deviation	(0)		.05	0.26		0.06
	Sample	(1)		(3)	(3)		(7)
	Void Ratio	2.50		NT	2.25		2.4
	Standard Deviation	(0)			(0.35)		(.17)
	Samples Tested	(1)			(3)		(4)
	Moisture Content (%)	95		113	103		103
	Standard Deviation	(0)		(16)	(23)		(9)
	Samples Tested	(1)		(3)	(3)		(7)
Hinuera Formation (CH) Material	Dry Density (tm^{-3})	0.7	NT	0.8	0.8	NT	0.8
	Standard Deviation	(0)		(0)	(0)		(0.06)
	Samples Tested	(1)		(3)	(3)		(7)
	Void Ratio	2.5		NT	2.2		2.35
	Standard Deviation	(0)			(0.1)		(.2)
	Samples Tested	(1)			(3)		(4)
	Moisture Content (%)	110		95	92		99
	Standard Deviation	(0)		(0)	(7.0)		(9)
	Samples Tested.	(1)		(3)	(3)		(7)

Samples from the impermeable silty clay layers in the Hinuera Formation indicate clay percentages of 65-80% (Figure A2.3) in batter log 2 decreasing to 45-50% in BL4.

Whangamarino Formation sediments from the batter logs are characteristic of fluviatile materials. Particle size distributions in the upper Whangamarino Formation are well graded and range from slightly sandy clayey silts to sandy silts (Figures A2.4-A2.7). The lenses of coarser grained sediments incised into the Whangamarino Formation during the post depositional period typically consist of slightly gravelly silty sands to muddy sands and clayey sandy silts (Figure A2.8).

Lower Aquifer material exposed in the NE sector of the highwall consist of slightly granular, medium to coarse sand (Figure A2.9) with a high pumice and greywacke content. Materials sampled from the paleochannel involved in the July 1986 batter failure are summarised in BL5 and (Figures A2.10-2.15). These materials grade up from a gravelly muddy sand into a gravelly sandy mud and overlying organic silts and muds. The coarsest size range of materials sampled from the basal Whangamarino Formation is from the paleochannel behind the wedge failure in Glen Afton Claystone. Channel material consisting of coarse gravelly medium to coarse sand (Figure A2.16).

On the basis of observations of the batter logs and laboratory results there is no significant variation in clay content of Tauranga Group materials across the highwall batters. It is suggested that the decrease in shear strength from NE to SW observed by Alldred (1984) is more likely to be the result of;

i) the decrease in dry density observed in Whangamarino Formation materials (section 3.2.2.1) implying a decrease in consolidation of these materials across the mine area from NE to SW.

and ii) loss of strength due to more intensive weathering of Whangamarino Formation materials over its entire thickness in the SW of the highwall.

<u>3.2.2.3</u> <u>Atterberg Limits</u>:

Figures 3.1 to 3.5 and Figure A3.1 summarise all Atterberg limit data for soil materials tested from batter logs 1-5. Data suggests that the fluviatile clayey silts and sandy silts of the Whangamarino Formation behave as CL (Unified Soil Classification

System) and CH type materials, with low to high plasticity. Organic clayey silts fall in the category of OH to CH.

3.2.2.4 Clay Mineralogy:

Results from XRD analysis suggests that kaolinite and illite are present in the <2um, of all the samples tested from the Whangamarino and Hinuera Formations collected in the batter logs, while quartz , cristobalite and feldspar are the most frequently observed non clay minerals. Smectite was found to occur throughout the samples from batterlogs 2 and 5, but is absent from batter log 1 between -8m R.L. and 0m R.L., which corresponds with the distribution of channel deposits incised into the Whangamarino Formation at this location.

Halloysite was identified in a sample from B.L.5 (0.5m R.L.), but was not identified in any other samples. The sample material was found to have a moisture content (above its liquid limit) and a void ratio (2.0) which is much higher than for other non organic materials. The material was found to display thixotropic behaviour upon sample disturbance, and has been observed to flow from the batter face during stripping operations by the bucketwheel.

Halloysite is the dominant clay mineral in the Kauroa-Hamilton Ash deposit (c.f. Walker,1965) exposed in the eastern batter slopes of the mine highwall. However samples from this deposit were not analysed.

The conclusion from XRD results is that there does not appear to be a significant variation in clay mineralogy between different sectors of the highwall. However as this study is purely qualitative it is not known if there are any variations in the proportions of clay minerals between different sectors of the highwall.

3.3 SHEAR STRENGTH TESTING:

3.3.1 Introduction: Block samples were collected from:

i) Location GR. 623350mN 332904mE (Figure 1 Map Pocket) to test the shear strength along the Te Kuiti-Tauranga Group contact in the southwestern sector of the mine highwall (sample 1);

ii) Location GR. 623528mN 333563mE (Figure 1 Map Pocket) in the eastern batter slopes, to test shear strength parameters along sub vertical jointing in Whangamarino Formation silt with orientation sub parallel to the highwall (sample II);

iii) Location GR. 623555mN 333530mE (Figure 1 Map Pocket) in the eastern batter slopes to test the shear strength along bedding plane defects in Whangamarino Formation siltstone (sample III)

All block samples were oriented in the field with respect to the highwall orientation and the sliding direction.

In addition a disturbed clay sample was collected for ring shear analysis. This sample was collected from GR.623270mN 332930mE at the base of a small (800-1000m^3) batter failure which occurred in July 1986 (section 4.2.2.5) material was taken from the toe of the slide at the contact of the Tauranga Group and Te Kuiti Group.

All samples for shear strength were double wrapped in plastic to prevent moisture loss during transportation and upon arrival in Christchurch were stored at 99% relative humidity in School of Engineering fog room until tested. The ring shear sample was forwarded to D.S.I.R. (Cromwell) NZ Geological Survey for residual strength analysis conducted by Mr. G Salt.

3.3.2 Test Procedures:

The direct shear test on sample 1 was carried out to obtain the drained peak shear strength parameters. Testing was carried out on four 60x60x20mm specimens in a non reversing Wykeham Farrance Shearbox in the Department of Geology University of Canterbury. Normal loads of 0.049kN, 0.151kN, 0.248kN and 0.343kN (14, 42, 69, and 95kPa respectively) were used.

Samples were consolidated 24 hours prior to shearing under saturated conditions. The Cv parameter could not be determined accurately, so that a conservative shearing rate of.002mm min^{-1} was adopted to ensure complete dissipation of pore pressures.

Direct shear tests on samples II and III were carried out to obtain the drained peak and residual strength parameters. Sample II specimens were sawcut to create artificial joints, and trimmed into the shearbox, keeping the relative orientations determined in the field. Sample III specimens were trimmed carefully into the box, again with regard to field orientation. In all cases the joint or bedding planes being tested were carefully aligned with the plane of shearing. Testing for each sample was carried out on four 100x100x20mm specimens in a reversing Wykeham Farrance shearbox. Normal loads of 0.5, 1, 2, and 4kN (50, 100, 200, and 400kpa respectively) were used.

Samples were consolidated 24 hours prior to testing under saturated conditions.

Shearing rates of 0.0072mm/min. were used for both samples. Peak strength was determined by first shearing under tension.

Residual strength parameters were approximated for sample II, by reversing the shearing directions. A total displacement of 40mm was carried out for each specimen, and the shear force versus displacement recorded. Time did not permit residual strength parameters for sample III to be determined.

Physical characterisation testing was carried out on the shear strength samples following the procedures outlined in section 3.2.1.

Semi quantitative clay analysis of shear strength samples was carried out using X-Ray Diffraction techniques. Clay mounts were prepared according to the procedures of Campbell (1975), Appendix 4a and Mr. R Soong (pers. comm.1986). The procedure for semi quantitative calculation is based on the method of Hume and Nelson (1982), Appendix 4b.

3.3.3 Test Results:

Table 3.2 summarises the results for material classification testing of shear strength samples.

Particle size distributions and diffractogram patterns for shear strength materials are illustrated in Figures A4.1 to A4.4 respectively.

Shear strength results are summarised in Table 3.2, while Figures A5.1 to A5.7 are X-Y plots illustrating displacement versus shear force, and failure envelopes based on plots of shear stress versus normal stress.

3.3.4 Discussion and Interpretation:

The shear strength measured along the unconformity surface, (C'=15kPa $\emptyset'=18^\circ$) in the southwestern sector of the highwall, is comparable to the shear strength parameters obtained by Mandeno, Chitty and Bell (1981), on borehole core from Ohinewai. A conclusion drawn from the test results of Ohinewai material is that all of the samples with low angles of friction ($\emptyset'<20^\circ$) are silty clays located near the base of the Tauranga Group. Most of these materials possessed relatively high cohesion (C'=34-165kPa) however materials from two boreholes d.9639 and d.9687 were found to possess low cohesion in addition to low friction angles, namely C'=5.5-10.6kPa $\emptyset'=19^\circ$-21° and

TABLE 3.2 : Summary of Shear Strength Results.

	cohesion C' (kPa)	friction angle	dry density	solid density	natural moisture	void ratio	grainsize S%	Z%	C%	LL	PI	Clay mineralogy Kao	Chl	Ill	Sm	I-S	I-C	V
SAMPLE I (unconformity) (surface)	15	18°	1.28	2.53	40	0.98						-	-	-	-	-	-	-
SAMPLE II (saw cut joint	0	24°	1.27	2.73	45	1.14	9	68	23	69	40	25	10	50	<10	<10	<10	10
SAMPLE III (beddingplane)	12	25°	1.27	2.73	45	1.14	9	68	23	69	40							
SAMPLE IV (ring shear)	0	14°			40		0	40	60	105	84	40	20	20	10	10	-	-

C′=22-26kPa Ø′=19°-26° located at between 2-4m and 16-20m respectively above the unconformity surface and overlying zones of lost core, which are assumed to imply zones of even lower shear strength.

The shear strength parameters obtained from the shearbox, C′=15kPa Ø′=18° are not necessarily representative for the whole unconformity surface due to the great variability in shear strength parameters observed in Tauranga Group materials. However it suggests the existence of low shear strength materials near the unconformity surface in the SW sector of the Weavers Opencast Mine highwall. The extent of weak shear strength clays needs to be further investigated.

The results of ring shear analysis (C=0kPa Ø′=14°) are considered to be in agreement with the measured physical properties of the soil. Kenney (1967 & 1977) suggests that the residual strengths of soil is dependent on i) mineral composition, ii) chemical state of the soil (cation exchange capacity), and iii) the relative volumes of clay mineral matrix and massive minerals. The ring shear sample is very fine grained with a clay fraction of 60%, and a plastic index of 80. Semi quantitative clay analysis suggests that the clay fraction consists of 40 % kaolinite, 20% illite, 20% chlorite, 10% smectite and less than 10% illite-smectite and illite-chlorite mixed-layer clays, Appendix 4b. On the basis of these results it is assumed the material represents highly weathered Glen Afton Claystone material at the top of the unconformity surface.

The shear strength obtained for sub vertical joints must be regarded as conservative since the defect was sawcut and smoothed before testing. Strength parameters obtained suggest C′=0kPa and Ø′=24°, and a residual Ø′=17°. Field observations suggest that strength parameters measured along the vertical joints and bedding planes are at peak strengths.

The shear strength along bedding planes in the Whangamarino Formation silt were measured as an alternative plane of failure to the unconformity surface along which shearing could take place. Shear strength along the bedding planes was measured to be C′=12kPa Ø′=25°. The cohesive parameter is considered to be apparent and a result of surface asperities interlocking (i angle equals 1-2°). The increase in friction angle (with respect to that obtained for the saw cut vertical joint) may reflect the slightly coarser grain size (very fine sandy silt) observed across the natural bedding plane defect.

3.4 SYNTHESIS:

On the basis of laboratory results the following conclusions can be drawn with respect to the engineering geological model of the highwall (Figure 2.23).

1) On the basis of laboratory results there is an apparent decrease in dry density and an increase in void ratio and moisture content from the NE to the SW sector of the highwall which is tentatively correlated with a decrease in overburden thickness and burial depths from NE to SW across the highwall.
2) Particle size distributions indicate that materials are typically well graded and hence of fluvial origin (c.f. Kelsey 1986). Hinuera Formation materials range from silty clays to gravelly sands. Fining upward sequences have relatively low clay contents, however silt contents may increase up to 80% in the sandy silts near the top of the sequence. This high silt content significantly reduces the vertical permeability of the Hinuera Formation, and also gives it the slight cohesion observed in the field.
3) Whangamarino Formation sediments are also typically well graded and the sequence that is observed in the mine highwall is regarded as fluviatile. Significant variation in grain size are recorded with each batterlog. However there is no clear evidence for a systematic decrease in clay content from NE to SW which may account for a decrease in shear strength, as suggested by Alldred (1984).
4) The principal clay minerals identified on the basis of qualitative XRD analysis are kaolinite, illite and smectite. Trends in the relative proportions of these minerals across the highwall were not determined, however there seems to be no significant difference in clay mineralogy between different sectors of the mine highwall.
5) Atterberg Limits determinations indicate no significant differences exist in the plasticity characteristics of materials from different batterlogs.
6) Analysis of shear strength along the unconformity surface indicate the presence of low shear strength materials ($C'=15kPa$ $\emptyset'=18^{\circ}$) at the base of the Tauranga Group in the southwestern sector of the highwall. However the results

are based on analysis of only one block sample, and further testing needs to be undertaken to assess the extent of low shear strength layers.

7) Shear strength parameters were measured along a sub horizontal bedding plane, as well as a sawcut vertical joints with values of $C'=12kPa$ $\emptyset'=25^{\circ}$ and $C'=0$ $\emptyset'=24^{\circ}$ respectively.

CHAPTER 4
BATTER INSTABILITY IN WEAVERS OPENCAST MINE HIGHWALL.

4.1 INTRODUCTION:
4.1.1 Objectives:

The main objective of this chapter is to analyse the data collected during the field and laboratory programme and relate this to batter instability observed in Weavers Opencast mine. The specific objectives are to;

a) relate observed modes of failure to rock and soil material factors and/or rock and soil mass factors;

b) determine the significance of shear strength across, and orientation of, the Te Kuiti-Tauranga Group contact on batter stability of Tauranga Group sediments;

c) establish a relationship between hydrogeological factors observed in the highwall and batter instability in Tauranga Group sediments; and

d) To investigate the possibility of wedge failures in Tauranga Group materials.

4.1.2 Classification:

Batter failures observed in the field were classified according to the scheme proposed by Varnes (1978), Table 4.1. This scheme uses type of movement and type of material as the main criteria for classification and was preferred to others (e.g. Sharpe 1938, Hutchinson 1968) which use criteria such as rate of movement and climatic factors. The classification scheme of Hoek and Bray (1981) was also used to distinguish between different types of translational sliding movements.

4.2 ANALYSIS OF OBSERVED MODES OF FAILURE
4.2.1 Te Kuiti Group:

Defect surveys and engineering geological mapping of the batters indicate that stability of the rock mass is controlled by shear strength along defect surfaces, rather than by the strength of the intact material.

TABLE 4.1:

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL	FEW UNITS	Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow	Earth flow
				(soil creep)	
COMPLEX			Combination of two or more principal types of movement		

from Varnes 1978

Fretting of material from the batter face in Glen Afton Claystone is recognised as a form of minor instability but is not significant to slope stability on a larger scale. Major batter instability in the Glen Afton Claystone and Waikato Coal Measures is a result of translational sliding failure (as defined by Varnes 1978) of which two types can be distinguished and these are discussed below.

4.2.1.1 Plane Failure:

Figure 4.1 illustrates a plane failure in the Waikato Coal Measures. Batter failure of this type vary from small scale involving several m^3 of rock material up to medium scale involving between 1000-2000m^3 of material. This scale of batter failure does not endanger the stability of the highwall, but provides a threat to machinery and personnel working close to the face. Observed failure planes were generally smooth and slickensided (Figure 4.2) indicating a definite sliding movement

Hoek and Bray (1981) suggest a number of geometric conditions must be satisfied for planar failures to occur:

i) the plane on which sliding occurs must strike within 20° of the batter face;

ii) the failure plane must daylight in the slope face;

iii) the dip of the failure plane must exceed the friction angle of the rock material; and

iv) release surfaces which provide negligible resistance to sliding must be present in the rock mass to define the lateral boundaries of the slide.

Figures 4.3a-b illustrates the two batter orientations in Weavers Opencast Mine in which the geometric conditions for plane failure are satisfied. These include batters with orientations of 154°/80° which parallel the dip direction of defect type A (155°±10°/54°±10°). Lateral release surfaces are provided by defect sets B and C, as well as by sub-vertical defect sets observed in the Glen Afton Claystone and Waikato Coal Measures.

Planar failures are also possible in batters with orientations 060°/80°, which parallel the dip direction of defect type C (058°±10°/50°±°10°)Lateral release surfaces are provided by defect sets A and its conjugate, as well as by the sub vertical joint sets.

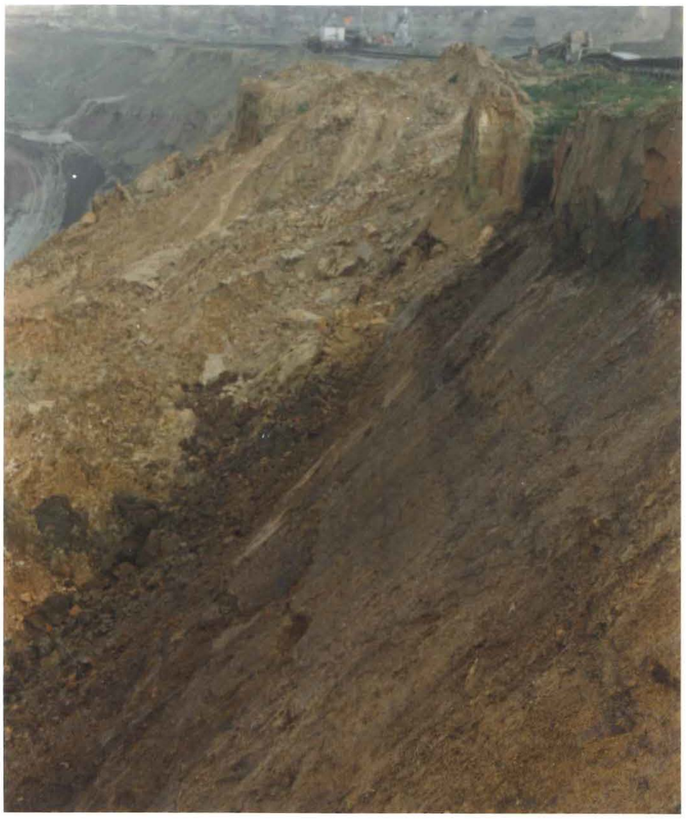
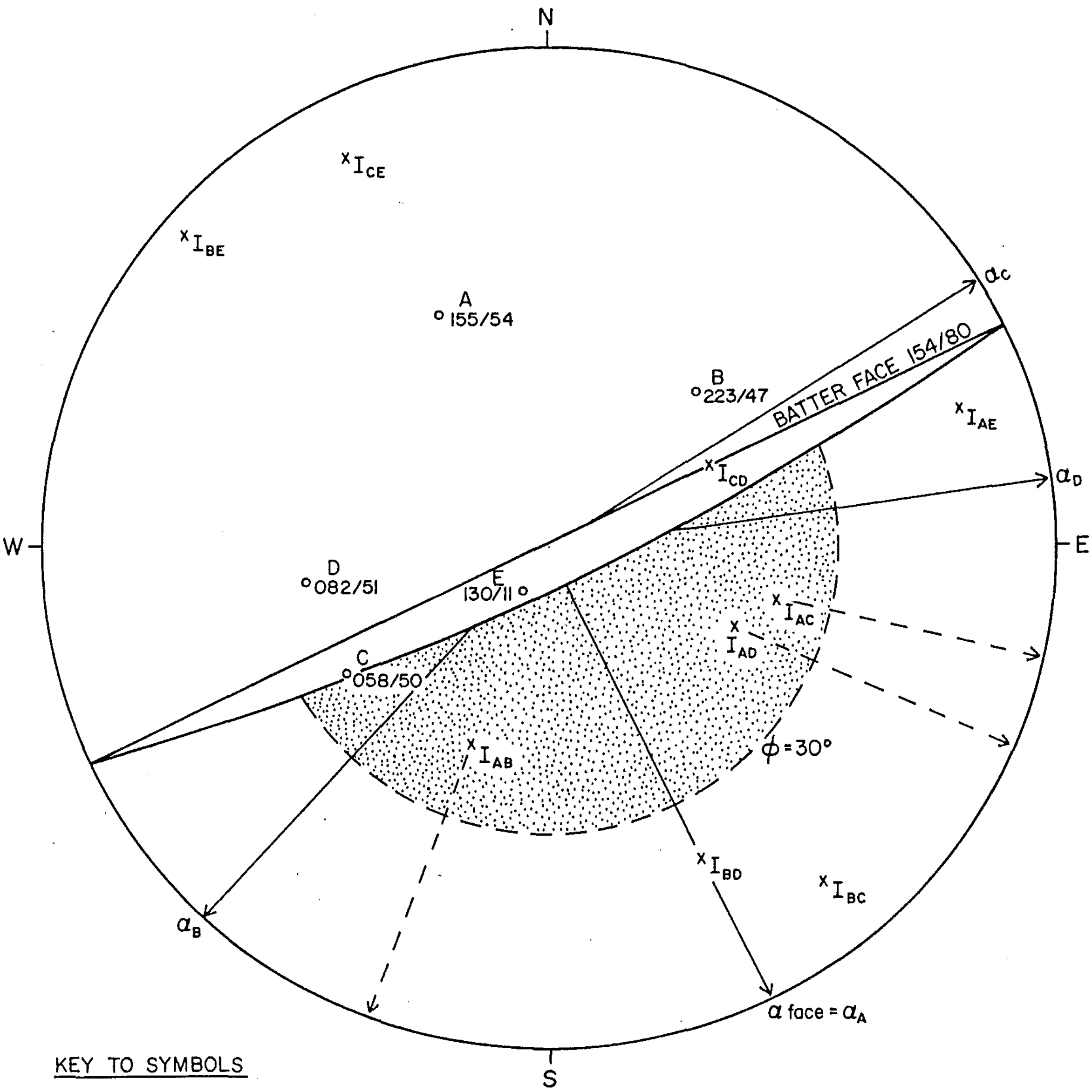


Figure 4.1: Plane Failure in Waikato Coal Measures resulting from sliding along joint plane striking parallel to and dipping out of batter face. (G.R. 333340mE 623465 mN) viewing west.

Figure 4.2: Slickensides on joint surface Fig. 4.1 looking southwards and down onto the joint surface.

Figure 4.3a : Stereographic analysis of Glen Afton claystone data illustrating potential for plane failures in batters dipping towards 150° - 160°



KEY TO SYMBOLS

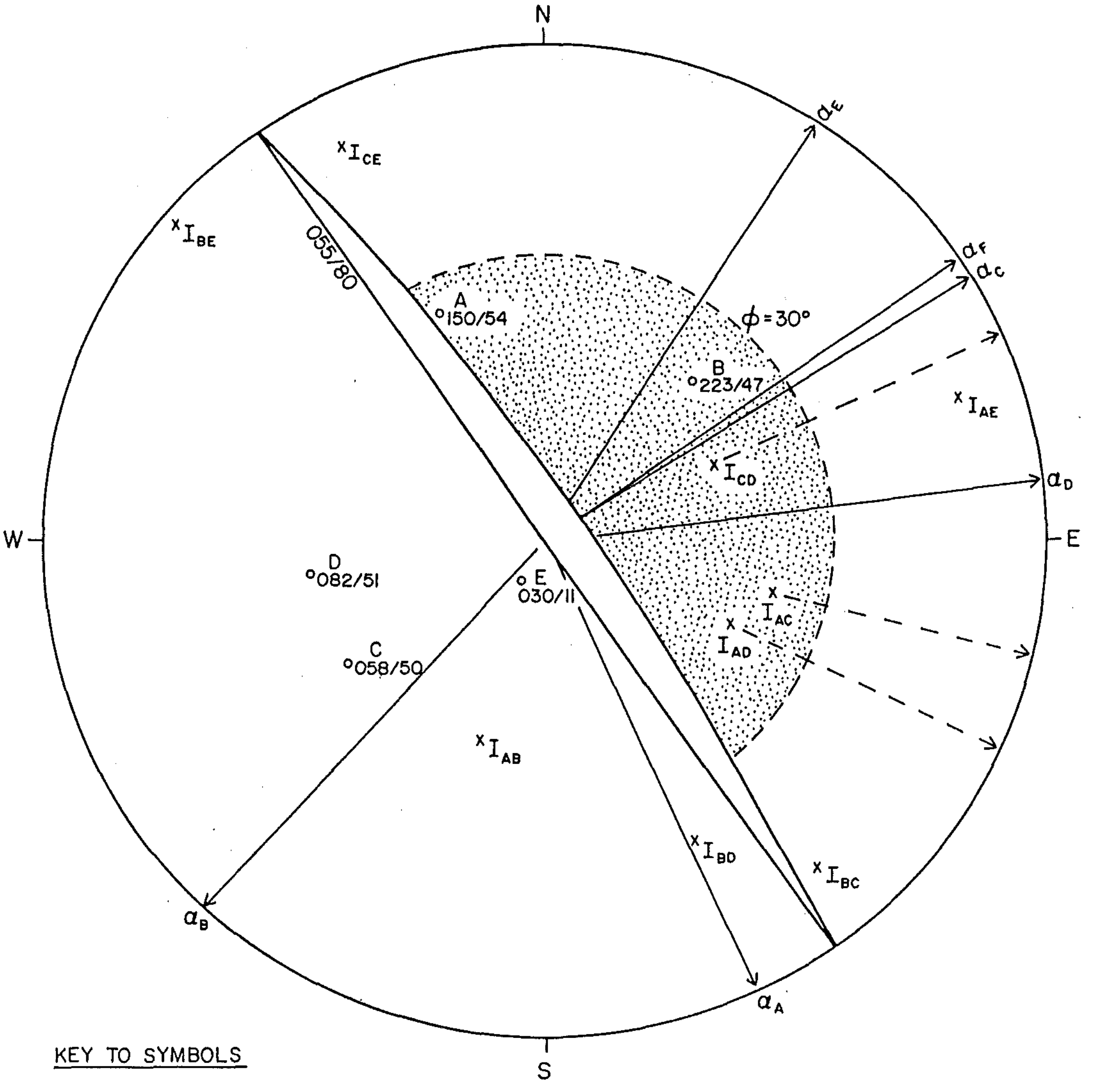
A = defect set A

α_A = dip direction of defect set A

I_{AB} = trend and plunge line of intersection of defect sets A and B

All dip directions and dip angles for defect sets are ± 10°

Figure 4.3b: Stereographic analysis of Glen Afton claystone data illustrating potential for plane failures in batters dipping towards 050° - 060°



KEY TO SYMBOLS

A = defect set A

α_A = dip direction of defect set A

I_{AB} = trend and plunge line of intersection of defect sets A and B

All dip directions and dip angles for defect sets are ± 10°

Figure 4.4 is a representation of the plane failure in Figure 4.1. Back analysis for this slide is difficult as the shear strength along the sliding surface, and pore pressure conditions at the time of failure are not accurately defined. However it is assumed on the basis of field observations that most batters have a short stand up time before failure occurs, suggesting that conditions along the sliding surface are marginally stable when the batter slopes are cut.

On the basis of a qualitative assessment of data, a number of factors are considered to be significant in producing this type of failure in the opencast highwall. An important factor is considered to be stress release of the rock mass after excavation of the batter slope. Firstly parting of defect surfaces enables water to enter defects and pore pressures to build up in tension cracks and along potential sliding surfaces. Secondly, stress release of the rock mass can cause minor displacements to take place along rock mass defects. Displacement along the defect surfaces can result in shearing through surface asperities and produce a decrease in shear strength along the defect surfaces. As removal of toe support after excavation significantly increases shear stress along the sliding surface, it is likely that even very minor reductions in shear strength along the sliding surface will result in batter failure.

4.2.1.2 Wedge Failure:

Figure 4.5 illustrates a large wedge failure in Glen Afton Claystone. Observed wedge failures varied from small scale to medium scale, involving up to 1000m^3 of rock material. At this scale they are significant because of the danger they pose to mine personnel and machinery working near the face.

The principal geometric requirements for wedge failure have been defined by Hoek and Bray (1981) as

i) sliding occurs along the line of intersection of two defect planes which daylight in the face, and

ii) that the dip of the line of intersection, is less than the dip of the batter face, but is greater than the friction angle of the rock material.

Field observations in Weavers Opencast Mine suggest that wedge failures as defined above occur most frequently in batters with an orientation of 130°/80°, resulting from the intersection of defect types A and C and A and D. These observations are supported by

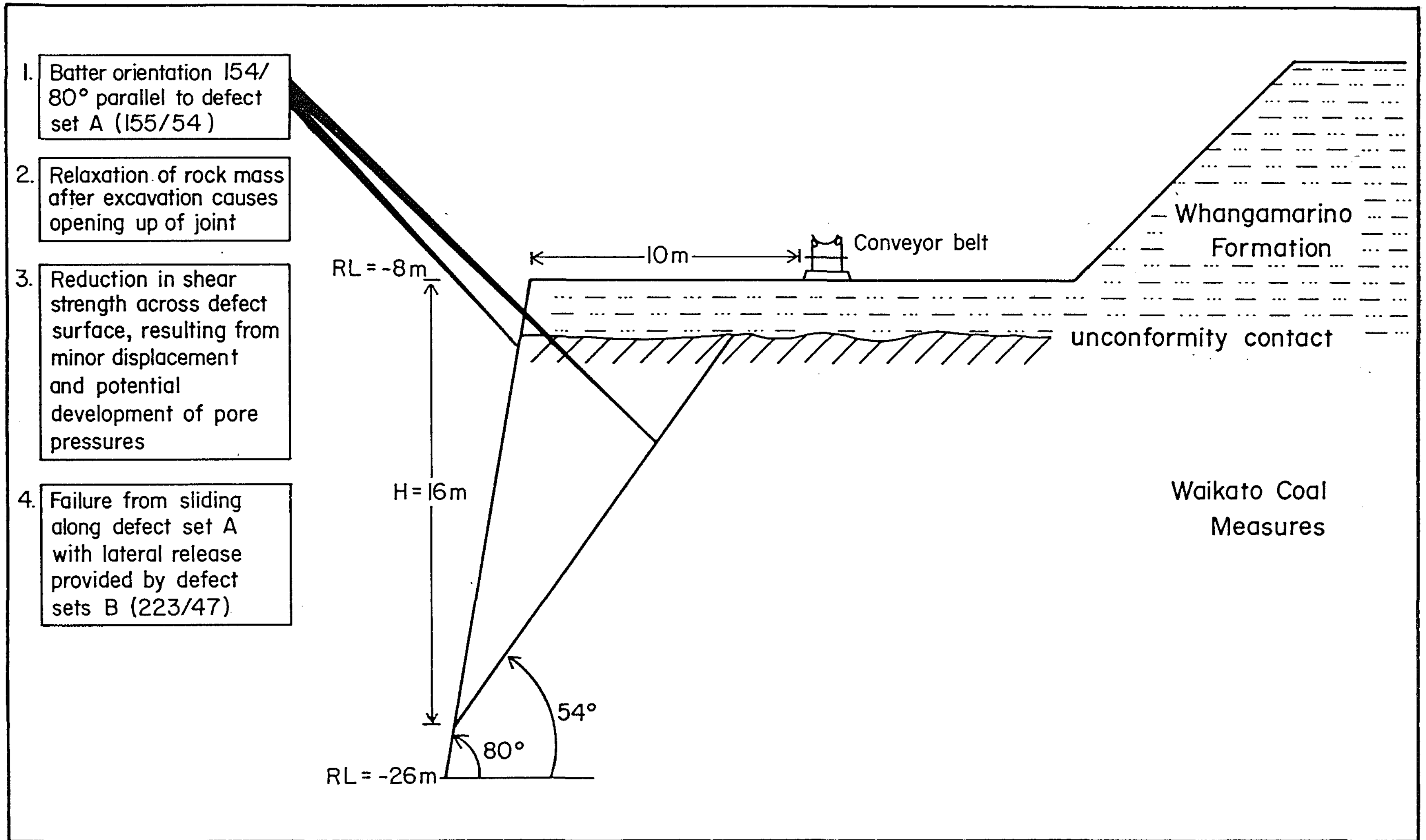


Figure 4.4 Factors contributing to plane failure in Te Kuiti Group Rocks

Figure 4.5: Wedge failure in Glen Afton Claystone resulting from sliding along line of intersection of two defect planes. Batter face orientation is towards 130 at 80, batter height is 9m. (G.R 332880mE 623190mN) viewing North.

stereographic analysis (Figure 4.6). Wedges formed by the intersection of defects A and B and C and D are not true wedge failures as defined by Hoek and Bray (1981). The stereonet indicates that the dip direction of defect planes A and D lie between the dip direction of the face and the respective lines of intersection, implying that failure occurs as a result of sliding along defects A and D respectively, while defects B and C act purely as release surfaces.

Wedges resulting from the intersection of defect sets B and C and B and D can also be distinguished in batters oriented 130°/80° (Figure 4.6). Stereographic analysis indicates however that the dip of the line of intersection is less than the friction angle assumed for the material (Ø'=30°) implying that these wedges are stable.

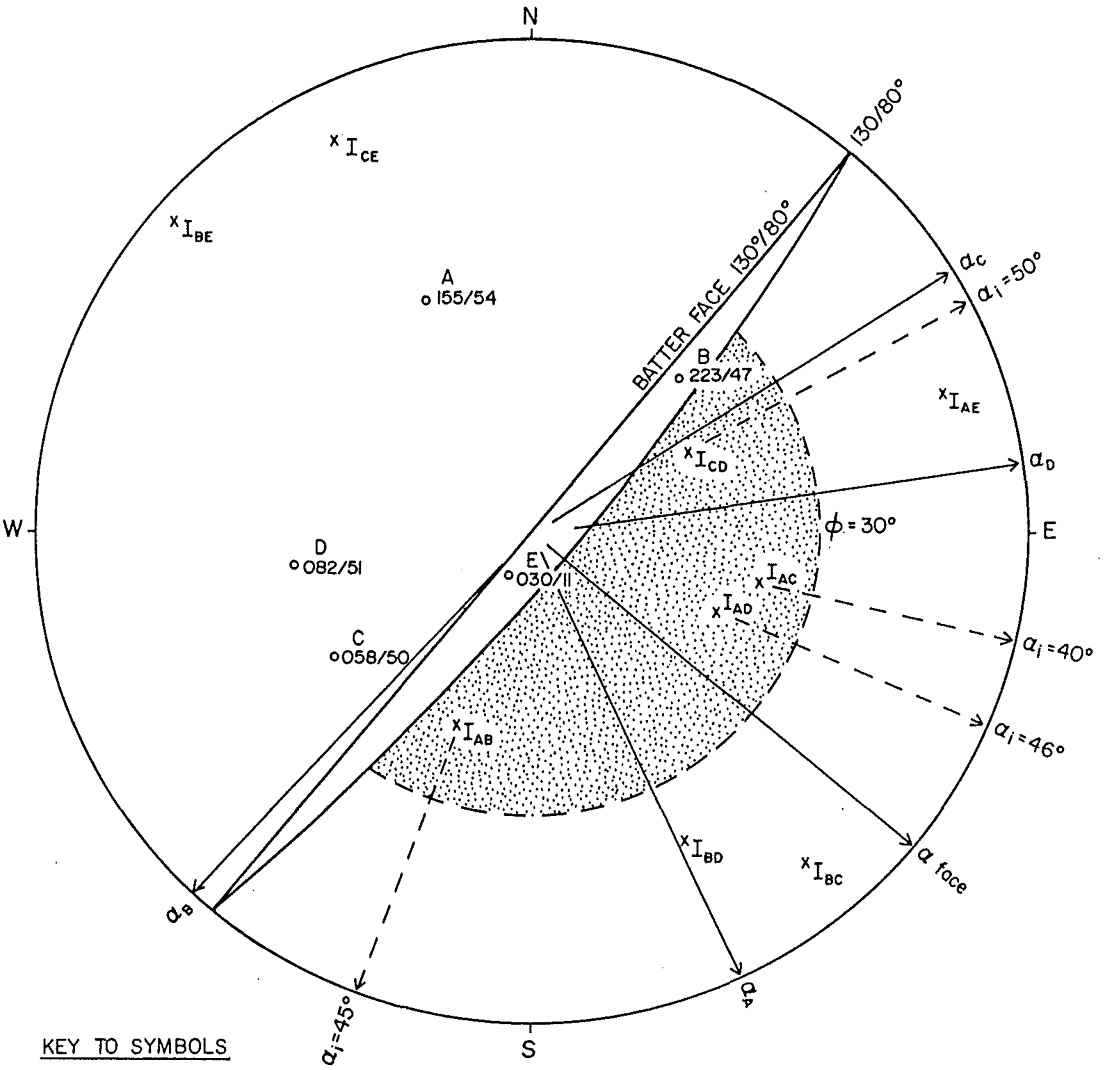
4.2.1.3 Wedge Analysis:

A back analysis of the wedge failure in Glen Afton Claystone (Figure 4.5) was carried out with the purpose of estimating the shear strength parameters along the defect planes. The procedure outlined by Hoek and Bray (1981 Pages 203-209) was used and calculations for the analysis are presented in Appendix 6,(all defect orientations are dip direction / dip angle). The geometry of the wedge as defined in the field is illustrated in Figure 4.7. Batter failure resulted from the intersection of two joint planes, oriented (160°/56°) and(053°/50°) The trend and plunge of the line of intersection is (102°/39°) out of a batter dipping towards 130° at 80°. The height of the batter face is 9m and the upper surface of the bench is approximately horizontal.

Field observation indicated the defect surfaces were smooth to slightly rough, with no evidence of cementation along their surface. Slickensides were present on one of the defect surfaces (053°/50°) but the slip directions were not determined.

A paleochannel was observed immediately above the wedge failure. Sediments in the channel were saturated and appear to have provided a seepage path for groundwater. The channel terminated at the back of the wedge failure where the two defect planes intersected in the bench surface, and provides the point where water can enter the wedge geometry. From these observations it is assumed that pore pressures influenced wedge stability, and that these would have been greatest during rain storm events when the discharge from the upper aquifer increases rapidly in response.

Figure 4.6 : Stereographic analysis of Glen Afton claystone data illustrating potential for wedge failures in batters dipping towards 130° - 140°



KEY TO SYMBOLS

A = defect set A

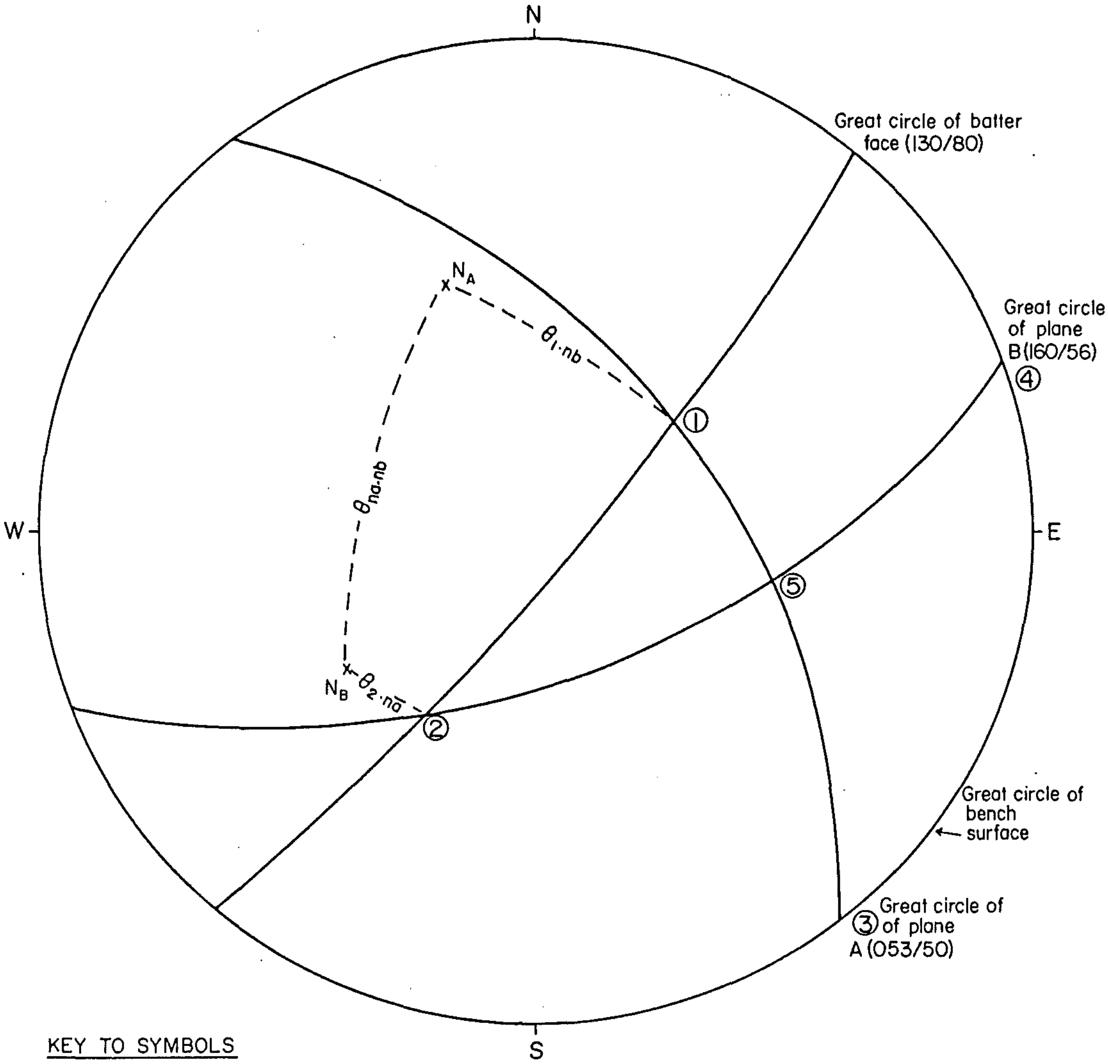
α_A = dip direction of defect set A

I_{AB} = trend and plunge line of intersection of defect sets A and B

All dip directions and dip angles for defect sets are ± 10°

Figure 4.7

BACK ANALYSIS OF MAJOR WEDGE FAILURE
GLEN AFTON CLAYSTONE, WEAVERS OPENCAST MINE



KEY TO SYMBOLS

① intersection of plane A (053/50) with slope face
② intersection of plane B (160/56) with slope face
③ intersection of plane A with bench surface
④ intersection of plane B with bench surface
⑤ intersection of planes A and B

N_A = pole to plane A
N_B = pole to plane B

Table 4.2 Summary of Wedge Analysis Data.

CASE I c'= 0 u= 0

ϕ°	c' (kPa)	F.O.S	REMARKS
25	-	0.76	Not possible, collapses immediately after batter is cut
30	-	0.94	" " " " "
35	-	1.13	

CASE II c'>0 u=0

ϕ	c'	F.O.S	REMARKS
25	5	1.03	
	10	1.30	
	15	1.57	
30	5	1.21	
	10	1.48	
	15	1.75	
35	5	1.41	
	10	1.68	
	15	1.95	

CASE III c'>0 u>0

ϕ	c'	F.O.S	REMARKS
25	5	0.65	
	10	0.92	
	15	1.19	Not possible, does not fail even at u Max
30	5	0.74	
	10	1.01	
	15	1.28	Not possible, does not fail even at u Max
35	5	0.84	
	10	1.11	Not possible, does not fail even at u Max
	15	1.38	" " " "

The following assumptions are made for the back analysis;

i) that the wedge failure is marginally stable ($F > 1.0$) when the slope is dry ($U=0$, where U = pore pressure).

ii) that wedge failure results from a built up of pore pressures along the defect surfaces.

The friction angle across defect surfaces in Glen Afton Claystone is assumed to lie in the range of $25^\circ < \emptyset' < 35^\circ$. The upper limit of this range is taken to be slightly less than the friction angle for intact Glen Afton Claystone $\emptyset'=36^\circ$ used by the M.O.W. (Frederickson 1985) during their stability analysis of the Weavers Opencast highwall, which is based on triaxial test results of core material from Weavers Opencast (Smith 1983) and Ohinewai (R.W.L. Consultants 1984). Three conditions are investigated, namely

i) dry slope with no cohesion;

ii) dry slope with cohesion;

iii) wet slope ($U > 0$), for conditions i) and ii)

The results are summarised in table 4.2 and give the following indications:

1) Friction angles in the range between 25°-32° can be ignored for the case $C'=0$ as these would not stand up during batter preparation. However angles in the range $\emptyset'=32^\circ$-35° and $C'=0$ are considered feasible as they maintain marginal stability when the slope is dry but fail with the development of pore pressures across the defect surfaces;

2) friction angles in the range 25°-30° are feasible if a cohesion factor of between 5-10kPa is assumed. These shear strength parameters provide stability when the wedge is dry, but fail with the development of pore pressures across defect surfaces; and

3) 0-12kPa should be regarded as the range of cohesive parameters that can reasonably be assumed for defects along the Glen Afton Claystone, as it can be seen that planes with cohesion parameters of 15kPa will not fail even during the development of maximum possible pore pressures.

4.2.1.4 Complex Failure Mechanisms:

Not all of the observed batter failures can be explained in terms of a simple planar or wedge type geometry. Figure 4.8 illustrates failure resulting from a D type defect ($075^\circ/54^\circ$) intersecting with a

Figure 4.8: Complex failure in Glen Afton Claystone.
1: high angle defect at back of failure;
2: D type defect
3: conchoidal fractures
4: low angle defect plane providing sliding surface
(G.R.332900mE 623208mN) viewing north.

lower angle defect (076°/38°) and a sub vertical defect at the back of the failure (155°/80°) apparently combining to overcome the intact rock shear strength of the Glen Afton Claystone as suggested by the conchoidal fractures on the opposing side of the failure. This is one example in which the rapid deterioration in material strength of the Tertiary materials (in response to wetting and drying) may have been a significant factor in enabling instability to take place. This particular example was observed at the moment the block fell from the face. Movement was very rapid and appeared to be the result of initial sliding, changing to a rock fall type mechanism as the underlying support was removed.

4.2.2 Tauranga Group:

On the basis of engineering geological field descriptions (following Bell and Pettinga 1984), Tauranga Group units classified as engineering geological soils. Failure modes in the poorly consolidated granular materials (Taupo Pumice Alluvium and Hinuera Formation) are controlled by the shear strength of the material as well as by seepage pressures and erosion of material from the batter face. While failure modes in the consolidated fine grained materials are controlled by the shear strength of the intact material, as well as by the shear strength along soil mass defects.

4.2.2.1 Piping Failures:

Piping failures observed in the Taupo Pumice Alluvium and Hinuera Formation result from entrainment and erosion of material from the batter face. Figure 4.9 illustrates the development of piping failures in the Hinuera Formation. Piping failures develop as a result of high seepage pressures in the silty sands where they overlie the thin impermeable silty clay layers in the Hinuera Formation. Pore pressure results in the disaggregation of sand and silt grains and their entrainment and erosion from the batter face. Continued erosion at critical localities in the batter face undermines the overlying materials and results in the formation of steep walled semi circular cavities at the batter surface. Although failures of this type are progressive and involve small volumes of material, the rate of batter erosion and subsequent retreat can be relatively rapid.

Figure 4.9: Piping failure in Hinuera Formation sands overlying Whangamarino Formation silty clays. Piping failure indicated by arrow.

4.2.2.2 Earth Falls:

Movements of this type (as defined by Varnes 1978) occur in the Hinuera Formation silty sands, the Kauroa and Hamilton ash deposits, and the clayey silts of the Whangamarino Formation.

Within the Hinuera Formation earth falls involving volumes ranging between 5-20m^3 can be observed, these provide no danger to mine personnel or machinery but present a hindrance for access along batter slopes and benches. Newly cut batter slopes up to 5m high can be observed to stand sub vertically for short periods of time (hours to days) as a result of negative pore pressures in the batter slopes, and the small cohesive factor resulting from the silt and clay content in the Hinuera Formation. Batters remain stable while negative pore pressures are maintained, however as the slope dries out negative pore pressures disappear and failure results from a loss of strength within the material, as the cohesive component and friction angle are too small to maintain stability against the force of gravity. Failure is observed as the sudden release of slabs of sands from the upper part of the batter face. The initial forward rotational movement from the face is followed by a free fall through the air as the dominant type of movement. The impact of the failed mass at the foot of the slope often transforms it to a wet mobile debris flow, which comes to rest at an angle much less than the internal angle of friction of the material.

Figure 4.10 illustrates a small scale batter failure involving approximately 100-200$m^3$of Kauroa and Hamilton Ash material. Debris at the toe of the slope suggests the material detached from the batter face at the back of the failure. No evidence for sliding movements could be found, and a falling mechanism is assumed for the failure. The most significant factor resulting in batter failure appears to have been an steep batter angle (70°) with pore pressures acting as a contributing factor.

A second failure of this type was observed in the Whangamarino Formation (Figure 4.11) which occurred at approximately the same time as the batter failure in Figure 4.10. Failure involved approximately 100-200m^3 of material from a paleochannel incised into the underlying silty clays. A steep batter angle and seepage pressures from the batter face are again assumed to be the main contributing factors. No further instability was associated with either of these failures after the initial movement.

Figure 4.10: Earth fall in Kauroa and Hamilton ash deposits. (G.R. 333540mE 623570mN) looking north.

Figure 4.11: Earth fall in Whangamarino Formation, (G.R. 333465mE 623575mN) viewing north. Batter height is 8m, volume of instability is c. 100 cu.metres.

4.2.2.3 Earth Topples:

Toppling failures are associated with the clayey silts of the Whangamarino Formation, and are controlled by the orientation of two sub vertical joint sets with orientations parallel and perpendicular to the orientation of the highwall (section 2.3.8.2) Toppling failures are generally small scale, with observed failures involving up to 1000m^3 of material.

The development of toppling failures is outlined in Figures 4.12-4.15 . Initially the joints are tight (Figure 4.12). However with the excavation of the batter face, relaxation of the soil mass occurs and joint sets open up (Figure 4.13) , resulting in the development of a tension crack parallel to the face (Figure 4.14) Progressive overbalancing of the block material occurs, until the centre of gravity is exceeded and failure occurs (Figure 4.15). Attempts have been made to stabilise joint blocks in the vicinity of the bucketwheel conveyor belt by placing wire netting across the bench surface and batter face, however these attempts have been largely unsuccessful.

4.2.2.4 Sliding Failures:

Sliding failures in Tauranga Group materials were observed to occur only in the southwestern sector of the mine highwall. A batter failure of 800-1000m^3 (Figure 4.16) took place after a period of heavy rainfall in July 1986. The failure plane could not be clearly defined, however the geometry of the slide suggests a rotational component. Engineering geological logging of materials exposed in the backscarp of the slide show a fining upward sequence from gravelly muddy sand at the base of the exposed scarp to an organic rich silty clay at the top of the sequence. Field observations therefore indicate that the failure involves a paleochannel deposit at the base of the Tauranga Group succession, directly overlying the unconformity surface. Significant quantities of water were expelled from the soil mass during the batter failure, and groundwater seepage was still observed to occur at the back of the slide scarp (-3mR.L.) two days after the failure had taken place. Clearly pore pressures are important in inducing instability, and the water table must have exceeded the observed seepage level during the rainstorm. It is assumed that the paleochannel acted as a seepage path for groundwater in the batter slopes, and that instability resulted from the development of high seepage pressures along the unconformity surface within the channel deposit during the rainstorm

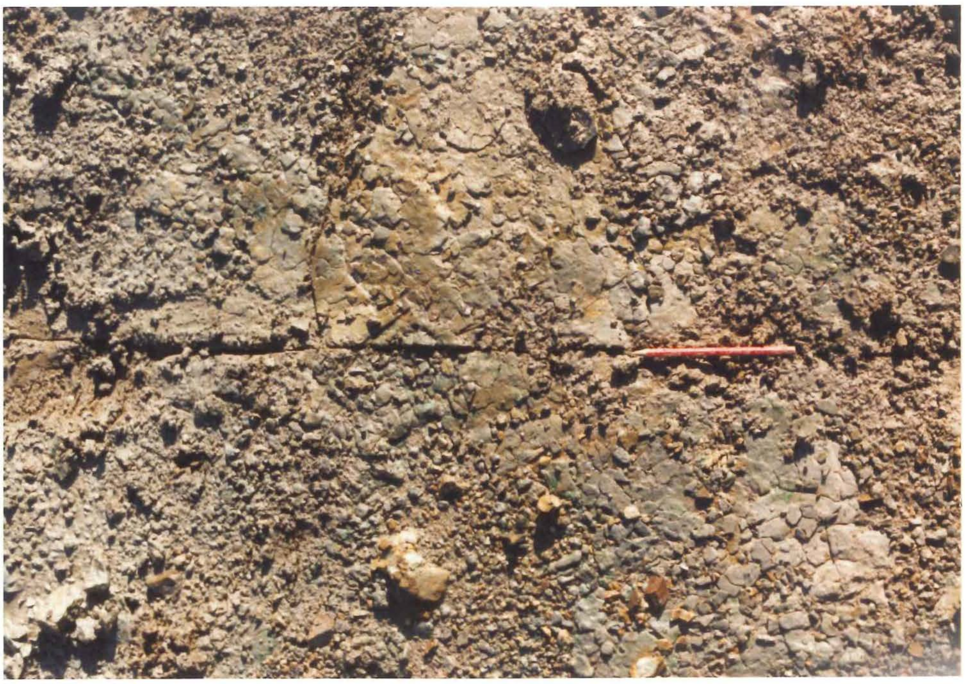


Figure 4.12: Sub vertical joint in Whangamarino Formation striking parallel to mine highwall exposed in bench surface c. 10m from batter edge. (G.R. 333380mE 623505mN) .

Figure 4.13: Subvertical joint in Whangamarino Formation 2m from batter edge. Joint aperture is opening up due to lateral stress release.

Figure 4.14: Sub vertical joint in Fig.4.13 illustrated in relation tobatter edge and conveyor belt. Trace of joint in bench surface is indicated by arrow and spade.

Figure 4.15: Toppling Failure in Tauranga Group. (G.R.333330mE 623480mN) viewing east.

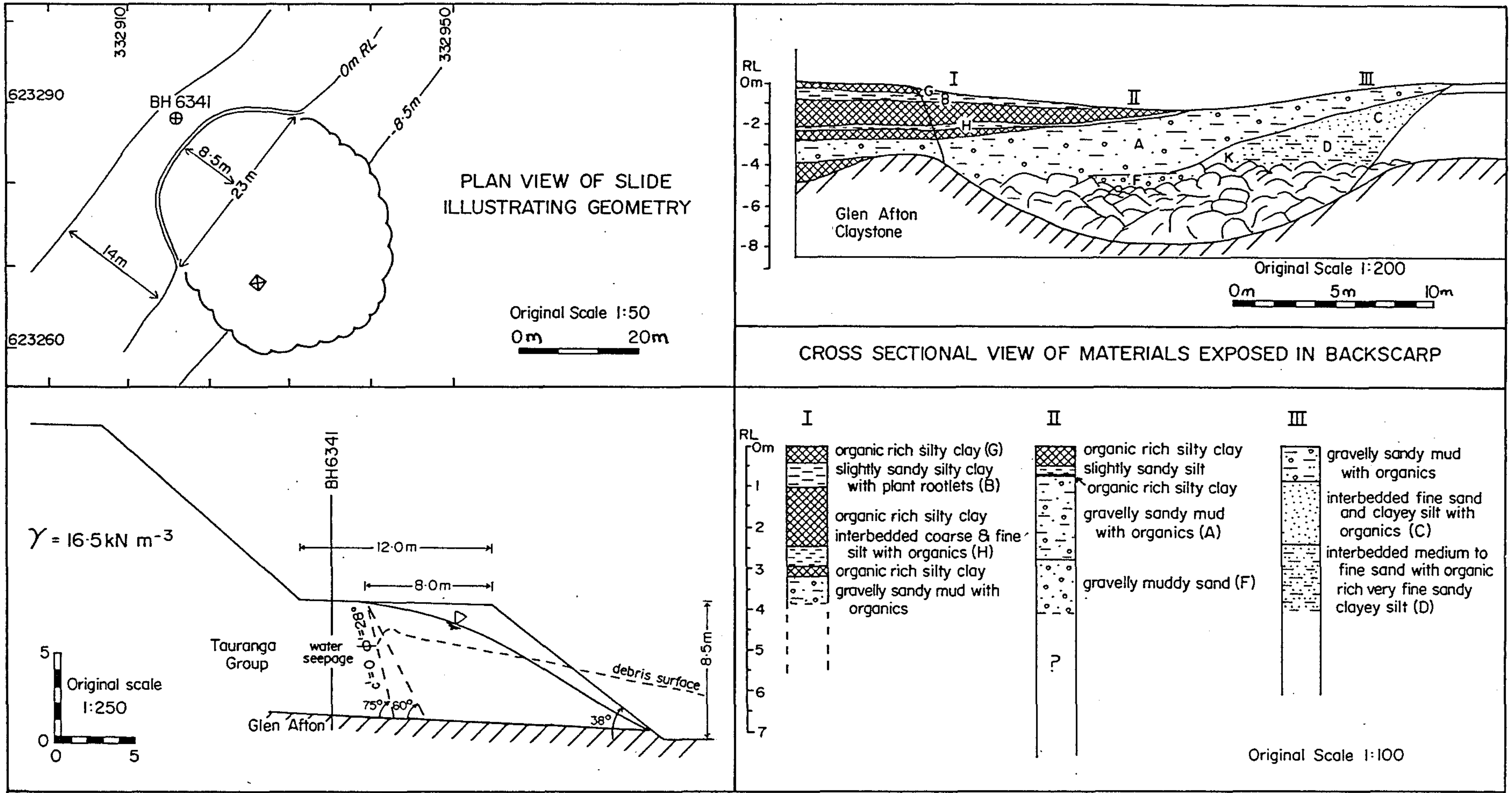


Figure 4.16: Small scale (1000 m^3) sliding failure in Tauranga Group sediments, July 1984

event.

The depth to the unconformity surface at the back of the failure was determined at -7mR.L (using a hand auger and survey data), and at the toe of the slide was observed at 0.4-0.5m above the bench level (-8.50m R.L.). On the basis of this data the unconformity surface was estimated to dip out of the face with a 3° slope.

Failure occurred by sliding along the unconformity accompanied by the development a remoulded, wet highly plastic clay at the contact of the Tauranga-Te Kuiti Groups. Ring shear analysis of this clay material (section 3.3) indicates residual strength parameters of $C'=0kPa$ $\emptyset'=14^\circ$.

On the basis of the available field and geotechnical data a very simple model was constructed (Figure 4.16) which was limited by the fact that neither the geometry of the sliding surface or the water table are well defined. However the model usefully indicated that residual strength parameters along the unconformity surface produces unreasonably low factors of safety, and suggests that peak strength parameters are present along the unconformity surface.

Figure 4.17 illustrates a batter failure that occurred in April-May 1987, in the south western sector of the highwall (Figure 2 Map Pocket) involving approximately $6000m^3$ of debris (9000 tonnes) over a distance of 40-50m of batter face. Batter height involved is approximately 8m. The information which could be obtained from this failure was limited as cleaning up operation had taken place prior to the author being able to inspect the failure. However the following may be noted:

1) The water apparent in Figure 4.17 is a result of discharge from the upper aquifer into a drain adjacent to the slide area. It is assumed from this that water infiltration into the lower Tauranga Group sediments may have been a factor contributing to the instability.
2) The location of the unconformity contact is indicated and suggests that shearing occurred on or close to the unconformity surface.
3) A significant factor involved in the failure appears to have been the sub vertical (to slightly overhanging) batter face cut by the bucketwheel (Figure 4.18).
4) The variability in shear strength of Tauranga Group materials along the unconformity surface is indicated by

Figure 4.17: Sliding failure in Whangamarino Formation in SW batter slopes, April 1987. Failure involved c.6000 cu. metres along 40-50m of batter face. Batter height is 8m. Position of Te Kuiti-Tauranga Group indicated by dotted line.
(G.R. 332880mE 623270mN) viewing north.

Figure 4.18: Bucketwheel excavator in operation adjacent to slide area (Fig. 4.17), note steep angle of cut batter face.

the ability of material in the adjacent batter to stand vertically.

On the basis of field evidence it can be tentatively suggested that the existence of locally high pore pressures in the slope, either as a result of natural groundwater infiltration , or due to infiltration of water from the drain was an important contributing factor to the batter failure, whilst removal of toe support for the slope by the bucketwheel excavator is assumed to have been the initiating factor.

4.3 ANALYSIS OF PAST BATTER FAILURES:

4.3.1 1980 Batter Failure:

A large scale batter failure within Tauranga Group materials (Figure 4.19) took place in November 1980. Air photos of this batter failure (SN 5796 A1-A3, 12 Dec.1980), indicate it is deep seated and involves an estimated 50,000m^3 of material over a length of 110m of batter face.

Factors involved in batter failures of this magnitude are complex, however evidence from air photos indicates that water seepage from drainage trenches located behind the batter face may have been a causative factor. Airphotos (SN 5744 A1-A3, May 1980) suggest the presence of a hummocked surface at the exact location where the batter failure took place in November 1980. The surface lies at the apex of a triangle formed by an older stream bed which feeds into the lake, and a cut drainage channel running subparallel to the highwall at a distance of 100m from the batter edge (Figure 4.19). Observation from the Dec.1980 photographs show that the drainage channel was excavated to a greater depth at some time during the period of May until November. In addition, air photos indicate that a pond (20m long by 15m wide) was excavated at a distance of 190m from the edge of the highwall, immediately behind the batter failure. Unfortunately the reason for the pond's excavation, or its depth are not known.

It is assumed that the hummocked surface indicates water saturated ground, and implies that a build up of pore pressures with a consequent reduction in shear strength of sediments in the slide area may have been the initiating factor that enabled batter failure to take place in November 1980.

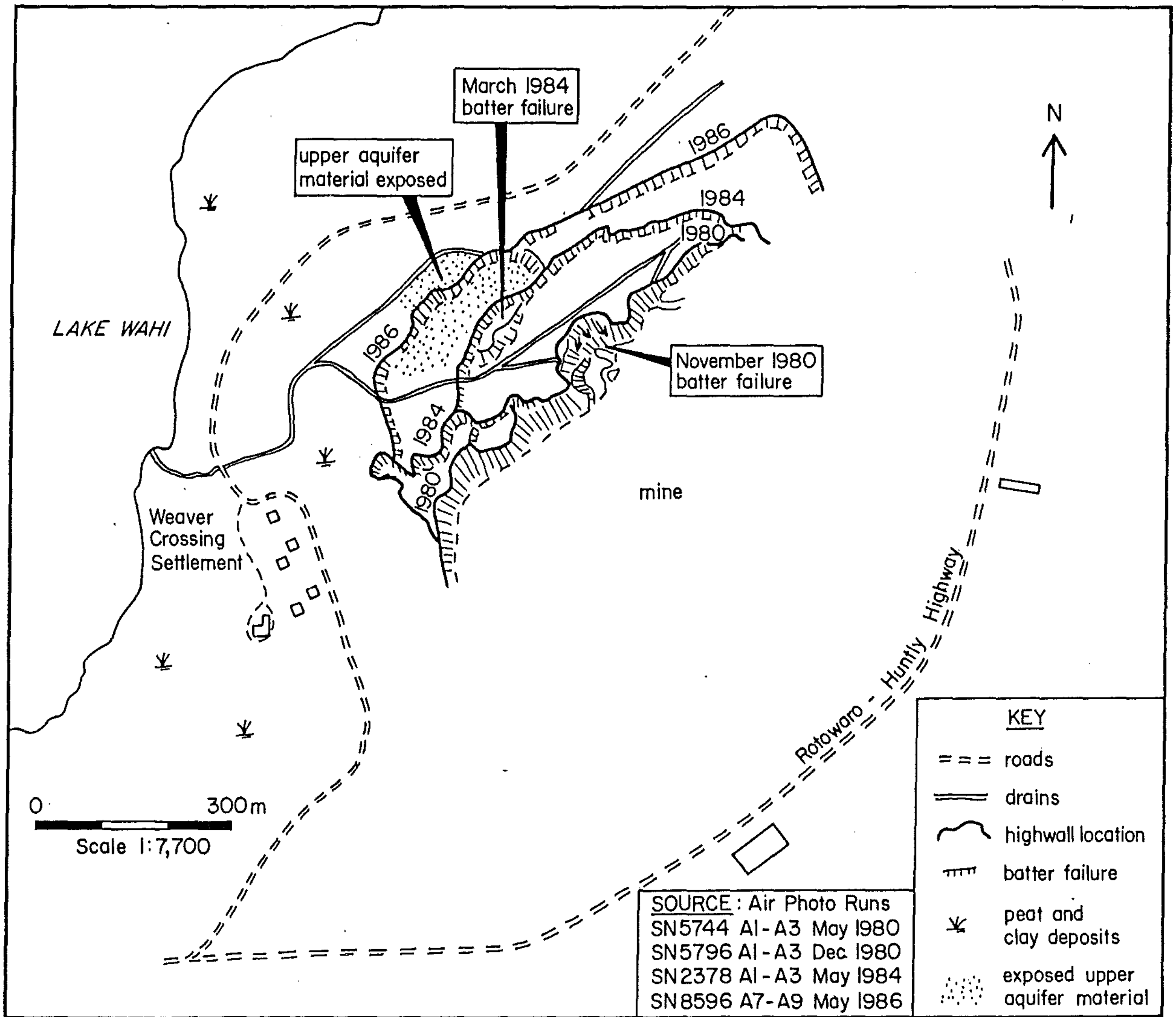


Figure 4.19: Large scale sliding failures in Tauranga Group sediments

4.3.2 1984 Batter Failure:

A second large scale batter failure within Tauranga Group Materials took place in March 1984. Air photo evidence indicates that the batter failure involves an estimated 40,000m^3 of material, which was released over 110m of batter face. The 1984 batter failure is located approximately 150m NW of the 1980 failure in the SW sector of the highwall, and occurred during the first two weeks of March after a period of heavy rainfall.

Factors contributing to the 1984 batter instability have been discussed previously by Alldred (1984a). A number of the suggestions made by him were found to be in agreement with independent field observations and air photo interpretation conducted during this study, and are included in the discussion.

The location of the 1980 and 1984 batter failure suggests that major batter instabilities in Tauranga group materials are restricted to the central and southwestern sectors of the highwall. No major batter instabilities have been associated with the northeastern highwall. This variation in large scale stability of Tauranga Group sediments can be related to a number of factors, the most important of which are:

1) the variation in hydrological condition across the highwall, from NE to SW, (as discussed in Chapter 2). In the NE and central sectors of the highwall the development of pore pressures in basal Tauranga Group is limited by the low permeable clay layers of the Hinuera Formation and the large relative thickness of the Whangamarino silty clay unit. Whilst in the SW sector of the mine area natural hydrogeological conditions exist which enable groundwater infiltration and the development of pore pressures above the base of the unconformity surface during rainstorm events. Two additional factors are suggested by Alldred (1984a) that may have contributed to the 1984 batter failure, these are related to mine activity, and include;

i) the stripping of low permeable peat and clay materials overlying Upper aquifer materials prior to batter excavation, which enables rapid infiltration of surface water into the Upper aquifer, and

ii) the excavation of drains behind of and parallel to highwall batters, which cut through the silty clay layers of the Hinuera Formation thereby increasing the vertical permeability of the Upper aquifer and increasing groundwater seepage into the basal whangamarino Formation.

2) the orientation and shear strength along the Te Kuiti-Tauranga Group contact. Survey data of the 1984 batter failure (Stone 1984) and correlation of this data with adjacent borehole information makes it possible to reconstruct the geometry and geology of the batter slope prior to its failure. A cross section of the batter slope (Figure 4.20) shows that the unconformity contact daylighted in the toe of the batter, and dipped out of the slope at 7°. This result is supported by the location of the 1984 batter failure on the structure contour map of the unconformity surface, which indicated that the batter failure is situated on the southern flank of the NE- SW striking spur of Glen Afton Claystone. On this basis it is strongly suggested that the batter failure in March 1984 involved shearing along the unconformity surface. This is consistent with field observations of smaller sliding failures observed in the pit during 1986 and 1987 as part of this study , (section 4.2.2.4), as well as with the results of shear strength analysis of block sample I (section 3.3.4) which indicates the presence of low shear strength materials at the base of the Tauranga Group immediately overlying the unconformity contact.

3) A decrease in shear strength of Whangamarino Formation from NE to SW resulting from i) greater consolidation of Whangamarino Formation materials in the NE sector of the highwall, as suggested by the decrease in void ratio observed from NE-SW across the highwall (section 3.2.2), and ii) more extensive weathering of Tauranga Group materials in the SW sector of the highwall as suggested by extensive iron oxide mottling and discolouration.

4.4 POTENTIAL FOR WEDGE FAILURE IN TAURANGA GROUP:

The mode of failure for large scale batter instabilities in Tauranga Group materials has not been clearly established. Previous stability investigations (Frederickson 1985) have assumed large scale batter failures result from rotational failure based on the assumption that the soil mass is intact and possesses no soil mass defects. However field observations show that persistent joint and bedding planes exist in the Whangamarino Formation, and that sliding failures involves shearing on or close to the unconformity surface. It was therefore decided to investigate the potential of wedge failures as an alternative mechanism to circular failures for producing large scale instabilities in Tauranga Group materials.

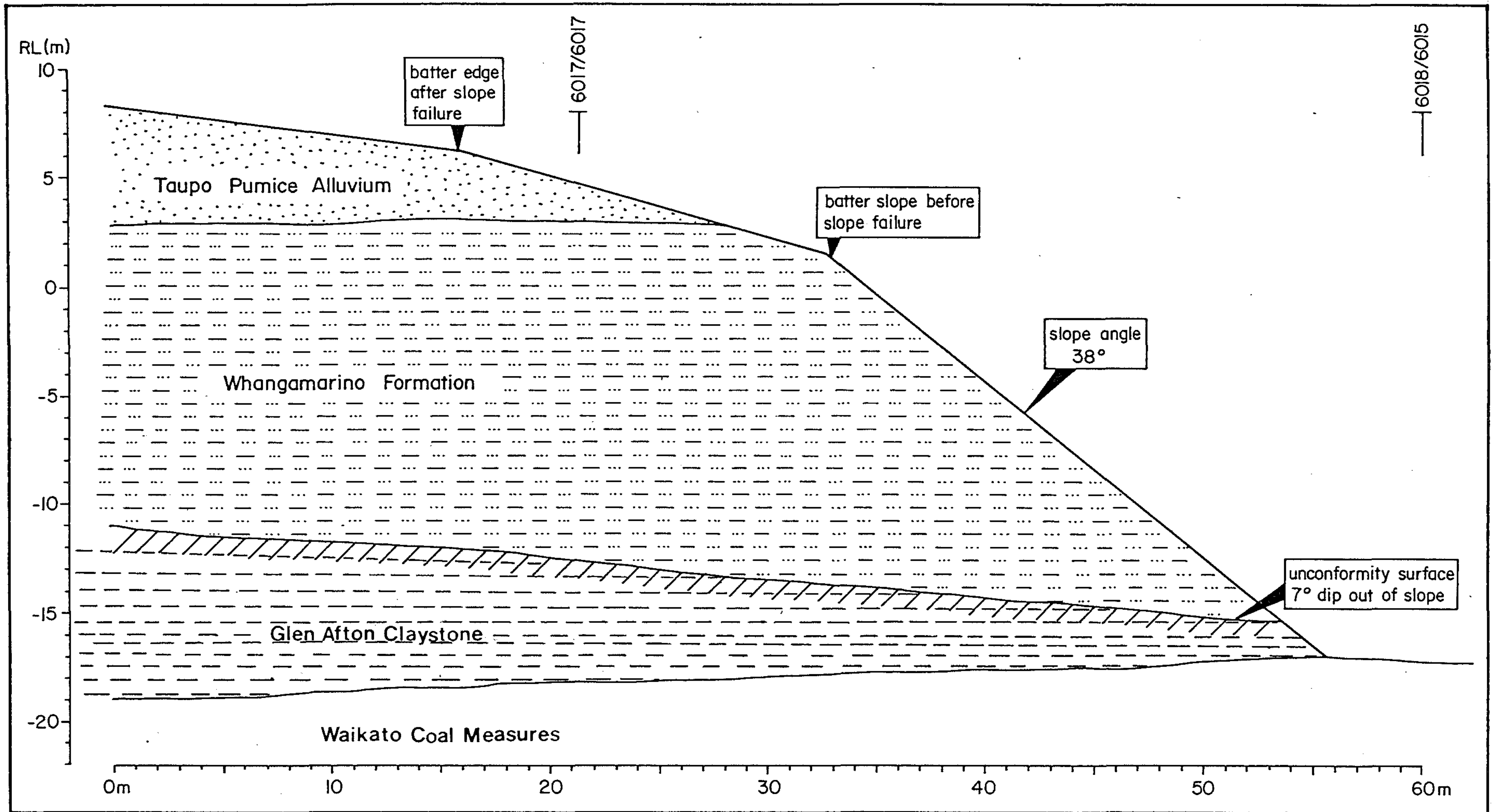


Figure 4.20 Cross-section illustrating geology and geometry of batter slope prior to failure in March 1984

ORIGINAL SCALE 1:200
(Based on survey data collected by D. Stone 1984)

Shear strength across joint and bedding plane defects in the Whangamarino Formation were measured, as well as the shear strength along the unconformity in the SW sector of the highwall. The strength parameters obtained (table 3.2) were used to back analyse the 1984 batter failure in terms of a wedge failure, using the information in Figure 4.20.

Two models were investigated :

i) wedge failure resulting from the intersection of sub vertical joints with the unconformity surface (Figure 4.21), and

ii) Wedge failure resulting from the intersection of sub vertical joints with a bedding plane defect located near the base of the Whangamarino Formation (Figure 4.22).

A major weakness in these models is that the presence of vertical joints in the Whangamarino Formation could not be verified in the SW sector of the highwall, due to the activity of the bucketwheel excavator which made the bench surface inaccessible. The presence of joints is therefore assumed on the basis that i) they can be observed to occur in the central and northeastern batter slopes, and ii) that Whangamarino Formation sediments in the SW sector of the highwall are sufficiently consolidated to maintain joint structures. However this assumption needs to be verified by detailed logging of batter slopes.

The analyses were carried out using a SARMA non vertical slice analysis. Results are presented in Tables (A7.1) in The potential for wedge failure along the unconformity surface is illustrated by the fact that the factor of safety drops to 1.0 as the water table rises to the position indicated in Figure 4.21 and further increases will produce batter failure.

Wedge failure involving sliding along the bedding plane is possible only if the watertable rises to intersect with batter slopes as indicated (in Figure4.22) producing a safety factor equal to 1.10. On this basis it is concluded that wedge failures involving sliding along the unconformity surface is more likely to occur.

The results of the analysis suggests that the potential for large scale wedge failures in Tauranga Group materials exists, and that this mode of failure needs to be further investigated. However it is necessary to verify the existence of joints in the SW batters of the Whangamarino Formation.

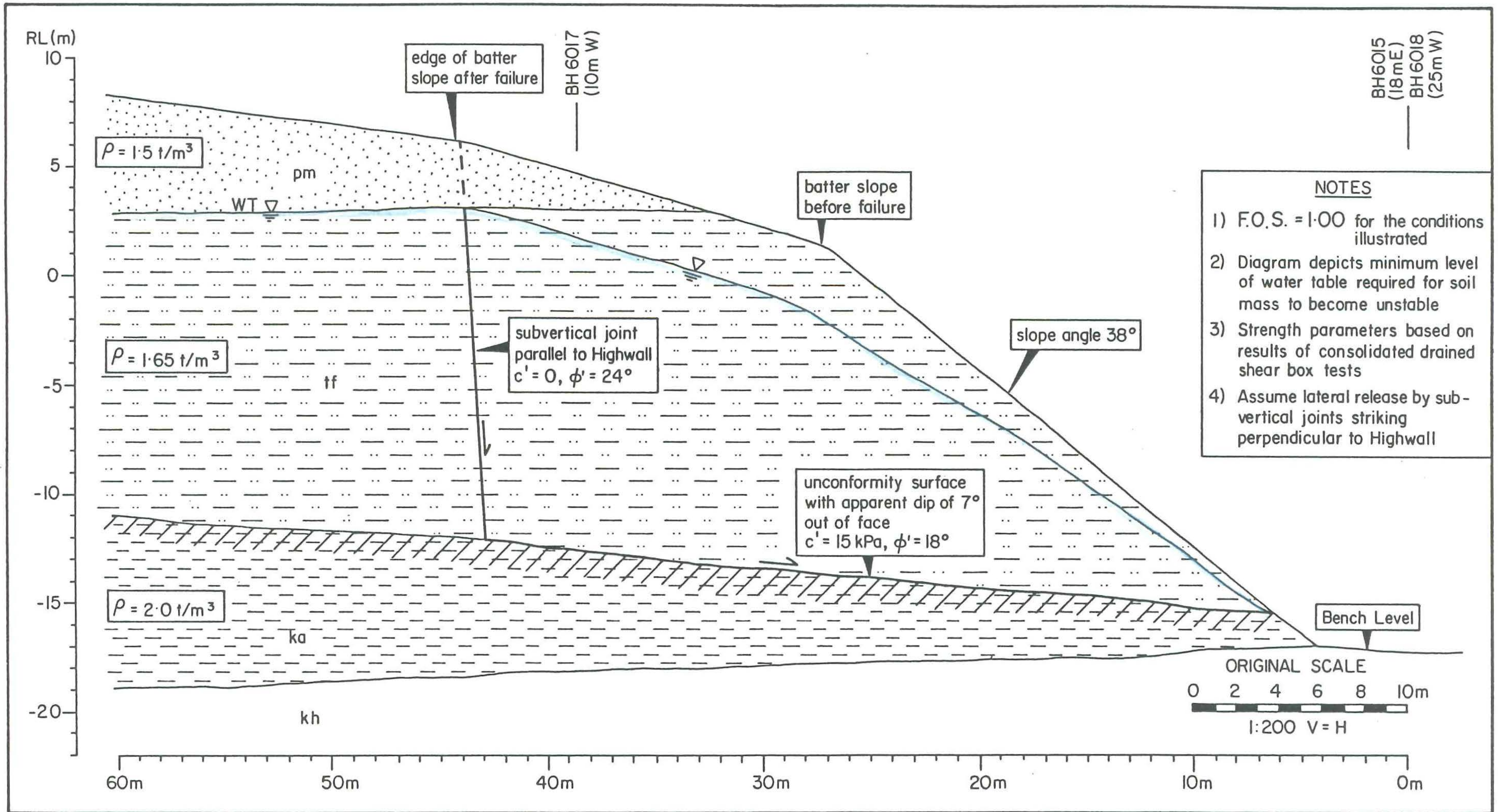


Figure 4.21 : Back analysis of 1984 batter failure assuming shearing along Te Kuiti - Tauranga Groups contact and lateral release by sub vertical joint sets

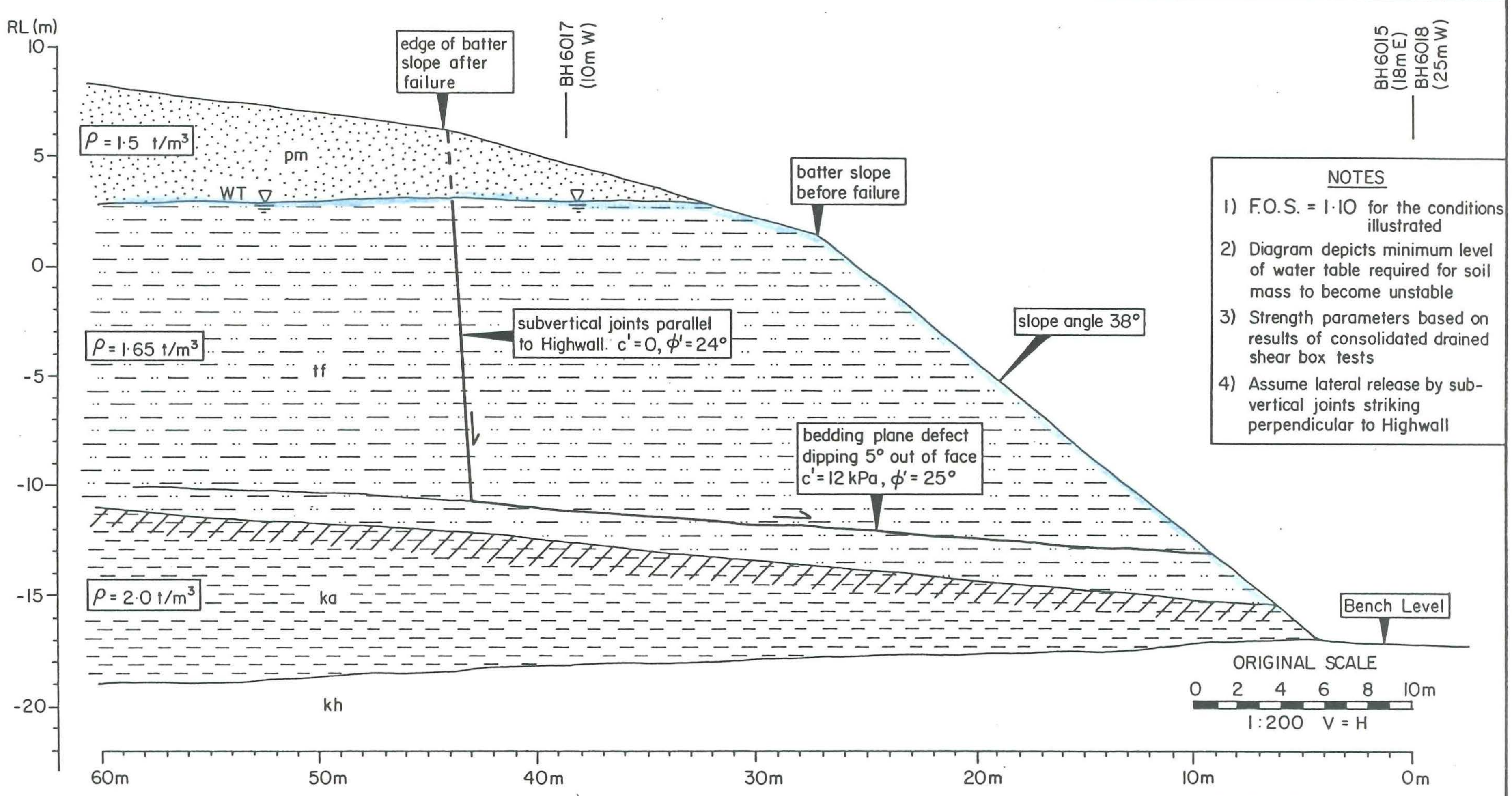


Figure 4.22 : Back analysis of 1984 batter failure assuming shearing along bedding plane and lateral release by sub vertical joints

4.5 SYNTHESIS:

1) The dominant type of batter instability in Te Kuiti Group rocks results from translational block sliding which is controlled by the orientation and shear strength of rock mass defects of which two types can be recognised;

i) plane failures, which are observed to occur in batters with orientations of $154^\circ/80^\circ$ and $060^\circ/80^\circ$ which parallel the strike of defect sets A and C respectively in both the Glen Afton Claystone and Waikato Coal Measures.

ii) Wedge failures which are observed to occur in batters with an orientation of $130^\circ/80^\circ$, and result from the intersection of defect sets A and C, as well as sets A and D.

2) Complex failures in Te Kuiti Group rocks, involving both sliding and falling type movements, and which may involve partial failure through intact rock can be recognised.

3) Fretting of material from batter surfaces in Te Kuiti Group materials is a minor form of instability recognised but is not significant on the larger scale.

4) The shear strength measured for joint planes in the Glen Afton claystone is estimated to lie in the range of C'=0-12kPa $\emptyset'=25^\circ-35^\circ$.

5) Tauranga Group materials are classified as engineering soils. The mass movement types and soil erosion mechanisms which can be recognised in the Tauranga Group are:

i) piping failures resulting from entrainment and erosion of material from the batter face, are restricted to the Hinuera Formation and Taupo Pumice Alluvium;

ii) earth falls in the Hinuera Formation, as well as in the consolidated cohesive soils of the Kauroa and Hamilton Ash deposits, and the Whangamarino Formation. Failures of this type resulted from a decrease in the shear strength of intact material in steep batters;

iii) earth topples in the clayey silts of the Whangamarino Formation in the central and NE sector of the highwall. Topples are controlled by two sub vertical defect sets, with orientation parallel and perpendicular to the highwall;

iv) sliding failures are restricted to the SW sector of the highwall and result from a complex of factors which include; i) infiltration of groundwater into basal Tauranga Group sediments; ii) low shear strength across, and unfavourable dip orientation of the unconformity surface; iii) a decrease in shear strength across the batter face in Whangamarino Formation sediments from NE to SW.

Additional factors resulting from mine activity can also be identified and include;

i) the stripping of low permeable peat and clay materials overlying upper aquifer materials;

ii) the excavation of drains behind of and parallel to the highwall.

6) The potential for wedge failure in Tauranga Group materials exists. The mechanism considered to be most likely involves shearing along the unconformity surface and lateral release by sub vertical joints. The validity of this model needs to be investigated further.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 CAUSES AND MECHANISMS OF BATTER FAILURE:

The engineering geological model of the mine highwall presented in Figure 5.1, summarises the causes and mechanisms of instability. Causes of batter instability, can be categorised according to i) engineering geological factors, ii) geotechnical factors, and iii) mining related factors.

5.1.1 Engineering Geological Factors:

1) Rock and Soil Material Factors: material factors of engineering rocks and soils contributing to batter instability in the mine highwall include;

a) the slake prone nature of Tertiary rock materials;

b) the poor consolidation and low cohesion of pumiceous silts, sands and gravels of the Hinuera Formation and Taupo Pumice Alluvium.

Instabilities related to these material factors are small scale and include, fretting of Tertiary materials from the batter face, and the development of piping failures, and earth falls within the Hinuera Formation and Taupo Pumice Alluvium. Instabilities of this type are significant to mining activity only in that they make access along batter slopes more difficult.

2) Rock and Soil Mass Factors: batter instability related to rock and soil mass factors include:

a) Orientation and shear strength of rock mass defects;

The following defect sets are recognised in Tertiary rocks:

i) defect sets A and G which parallel the strike of the highwall and the strike of the major NE-SW striking fault in the mine extension area;

ii) conjugate set B and C which strike at right angles to the highwall, and parallel to the major NNE-SSW striking fault in the mine extension area;

iii) conjugate set D and E in the Glen Afton Claystone which strike at 50°-70° to the highwall;

iv) defect set H in the Waikato Coal Measure Strata, which strikes at 70°-80° into the highwall and dips into the batter face;

v) defect set F which includes bedding orientations and low angle shear zones which dip c.10°N-NE into the highwall.

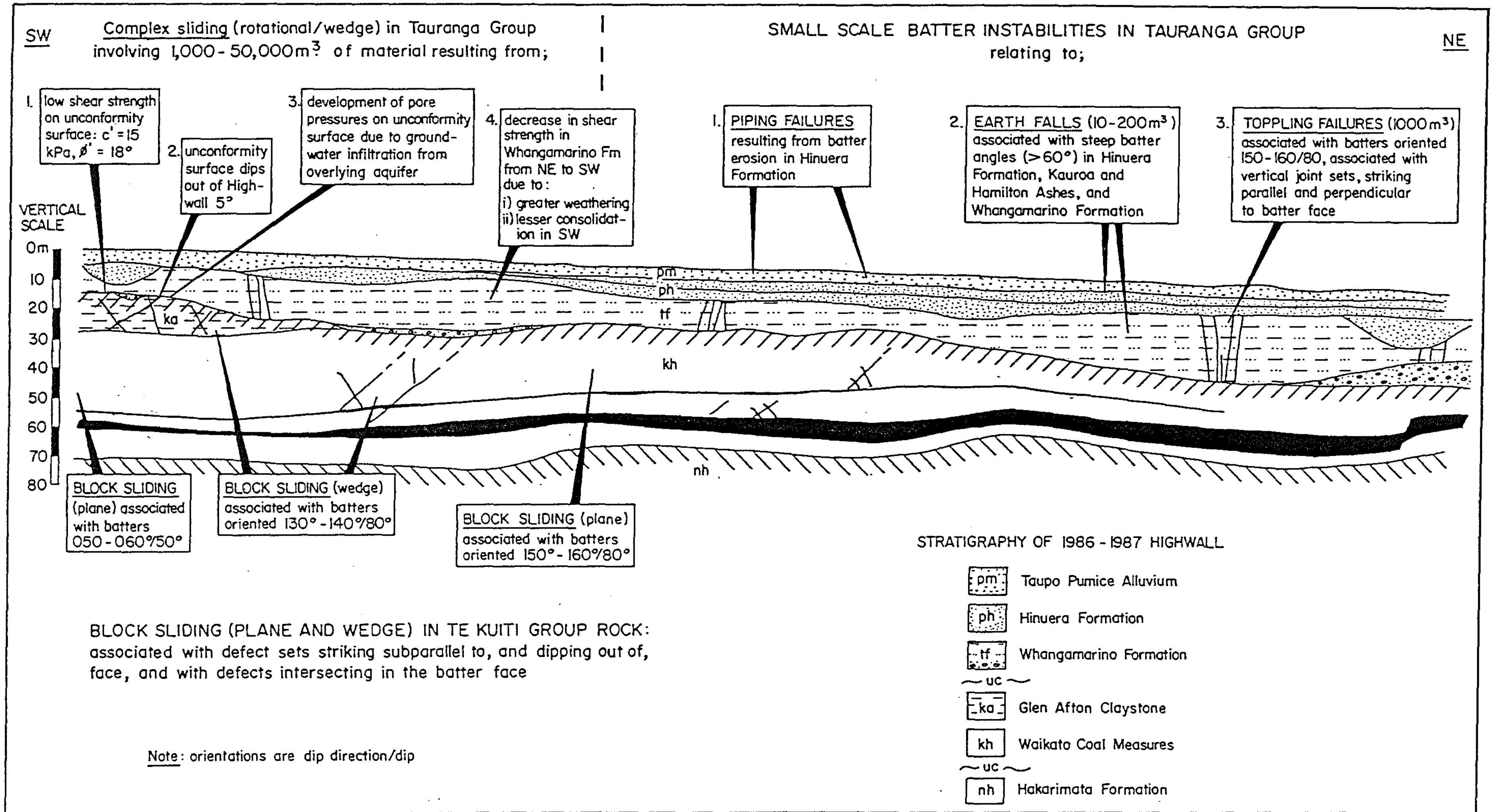


Figure 5.1 Schematic Engineering Geological Site Model

The dominant failure mechanism in Te Kuiti Group rocks is translational sliding, of which the following types are observed:

i) plane failures; occur in batters with an orientation of 150°-160°/80° and 060°-070°/80° which parallel the strike of defect sets A and C respectively in both the Glen Afton Claystone and Waikato Coal Measures;

ii) wedge failures occur in batters with an orientation of 130°-140°/80° and result from the intersection of defect sets A and C, as well as A and D ;

ii) complex failures involving both sliding and falling type movements can also be recognised.

Block slides occur on a scale varying from several cubic metres to 1000-2000m^3 and are potentially hazardous to mine personnel and machinery.

Back analysis of a wedge failure in Glen Afton Claystone indicates that strength parameters across joint surfaces lie in the range C′=0-12kPa Ø′=25°-35°.

b) <u>Orientation and shear strength of soil mass defects</u>: Two sub vertical joint sets are recognised in the Whangamarino Formation;

i) set Z striking parallel to the highwall; and

ii) set Y striking perpendicular to the highwall.

A set of sub horizontal bedding plane defects can also be recognised.

The dominant failure mechanism associated with soil mass defects are toppling failures in the central and NE batter slopes, which range in scale up to 1000m^3, and are potentially hazardous to mine personnel and machinery.

Strength parameters for joint and bedding planes in the Whangamarino Formation, as determined from shear strength analyses conducted during this study, are C′=0kPa Ø′= 24° and C′=12kPa Ø′=25° respectively.

3) <u>Factors Relating to the Rock and Soil Mass Contact</u>:

Engineering geological factors which influence strength along the Te Kuiti-Tauranga Groups contact are;

a) <u>Hydrogeological conditions</u>:

in the SW sector of the mine area infiltration of groundwater during rainstorms produces an increase in pore pressures above the unconformity surface, due to;

i) the high vertical permeability of the upper aquifer;

ii) the small relative thickness of the Whangamarino Formation aquiclude;

iii) the presence of permeable lenses within the aquiclude;

b) Adverse Dip orientation with respect to the highwall:

In the SW sector of the mine area paleorelief on the unconformity surface is dominated by a paleoridge of Glen Afton Claystone, which dips out of the batter face at 5°.

5.1.2 Geotechnical Factors:

Geotechnical factors considered to influence batter stability include;

1) Low shear strength along the Te Kuiti-Tauranga Group unconformity surface. Field observations indicate that Glen Afton Claystone and Waikato Coal Measure strata underlying the unconformity surface are often highly weathered. Shear strength analysis of a sample from the contact between Glen Afton Claystone and the Whangamarino Formation in the SW sector of the mine highwall indicate a relatively low shear strength of C′=15kPa Ø′=18°.

2) Decrease in shear strength of the Whangamarino Formation from over 300kPa in the NE to 65 kPa in the SW of the mine area. This is considered to reflect, i) more intensive weathering of the Whangamarino Formation in the SW sector of the mine highwall,and ii) a decrease in consolidation in the Whangamarino Formation as indicated by a decrease in the void ratio from 1.26 in the NE sector to 1.0 in the SW sector of the mine area.

5.1.3 Mining Related Factors:

Mining related factors which affect batter stability include:

1) Batter Design: instability of batters standing in excess of 60°is recorded for Hinuera Formation sands, as well as the clayey silts of the Kauroa and Hamilton Ash deposits, and the Whangamarino Formation. A medium size batter failure (6000m^3) in the SW sector of the highwall during 1987 is attributed to the height (8m) and steepness (90°) of the batter cut by the newly commissioned bucketwheel excavator.

2) Stripping of Low Permeability Sediments:
Removal of low permeabilty peat and clayey sediments

overlying the upper aquifer, as well as the excavation of drains through the low permeability clayey layers behind of and parallel to the highwall, are considered to be additional factors contributing to major batter failures in the past (March 1984, November 1980).

5.2 CONTROL OF BATTER STABILITY PROBLEMS MINE

Slope stability problems in Weavers can be controlled by ;

1) Controlling groundwater infiltration into basal Tauranga Group sediments. Dewatering of the upper aquifer has been attempted in the past but has met with only limited success due to the low vertical permeability of the aquifer in the NE and central batter slopes. At the present time infiltration of surface runoff is being controlled by leaving the low permeability clay and peat layer overlying the upper aquifer intact.
2) Reducing batter height. The scale of future batter instability in both Tauranga and Te Kuiti Groups materials can be controlled by reducing batter height. This is considered to be the most suitable solution while mining activity continues. Vertical batter faces are compatible with the operation of the bucketwheel excavator and are the least time consuming to cut.
3) Alternative solutions for improving batter stability including decreasing batter slope angles, or engineering solutions such as rock bolting of unstable rock masses are considered more suitable for the design of batter slopes in the final highwall.

5.3 RECOMMENDATIONS FOR FURTHER INVESTIGATION

The following recommendations are made for further investigation/monitoring:

1) Detailed batter logging of the Whangamarino Formation in the SW sector of the mine highwall, to determine the likelihood of large scale batter instability in Tauranga Group sediments by way of wedge failure as an alternative failure mechanism for large scale batter instability in Tauranga Group sediments. In particular it is necessary to verify the presence of sub vertical joint sets.

2) Further shear strength testing of the Te Kuiti Tauranga Group unconformity surface is required to determine more representative shear strength parameters.
3) To define piezometric pressures that may develop above the Te Kuiti-Tauranga Group unconformity surface, as a result of groundwater infiltration from the overlying aquifer, particularly in the SW sector of the mine area where the aquifer has a high vertical permeability.
4) To quantify more accurately the shear strength parameters across defect surfaces in both the Tauranga Group and Te Kuiti Group, in order to provide geotechnical information for batter design.
5) To periodically conduct defect surveys and batter logs for further geotechnical data collection, as the highwall advances northwards. This should be carried out preferably by a person with an engineering geological background.

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APPENDIX 1
RAW DATA DEFECT SURVEYS

Waikato Coal Measures
Stereographic Plot of Raw Data (Feb. 1986)

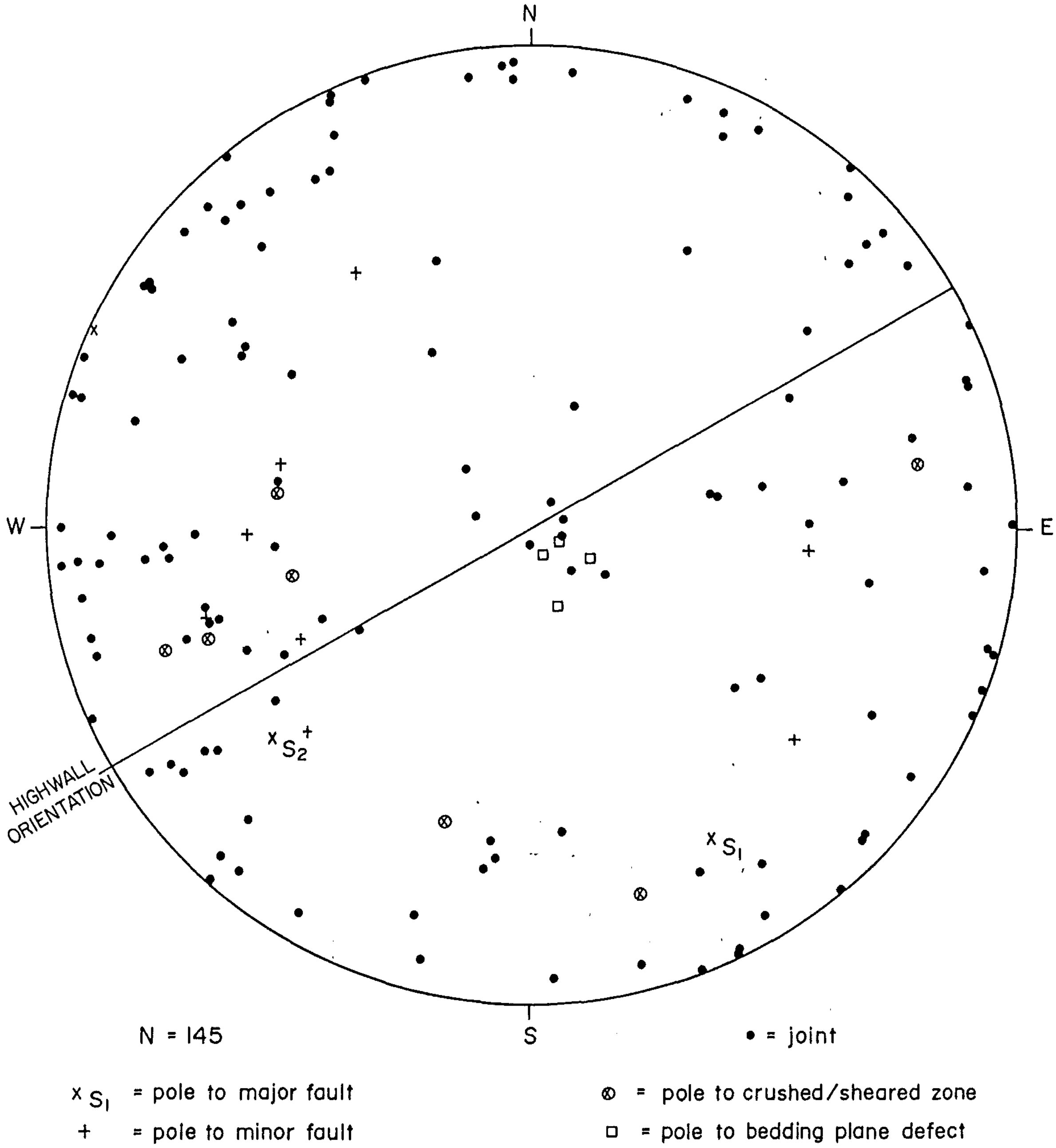


Figure A1.1

Waikato Coal Measures
Stereographic Plot of Raw Data (Hyde 1986)

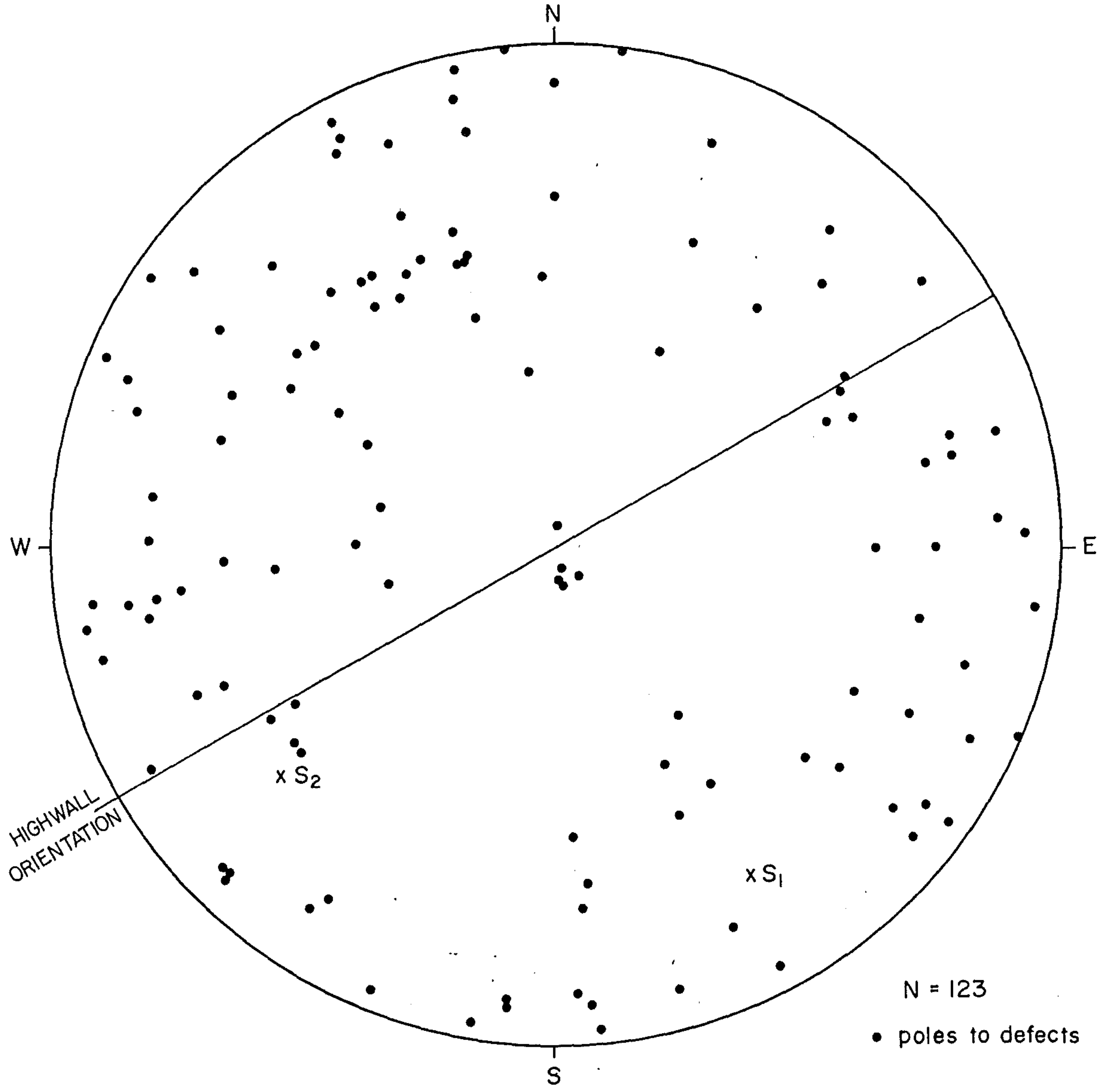


Figure A1·2

Glen Afton Claystone
Stereographic Plot of Raw Data

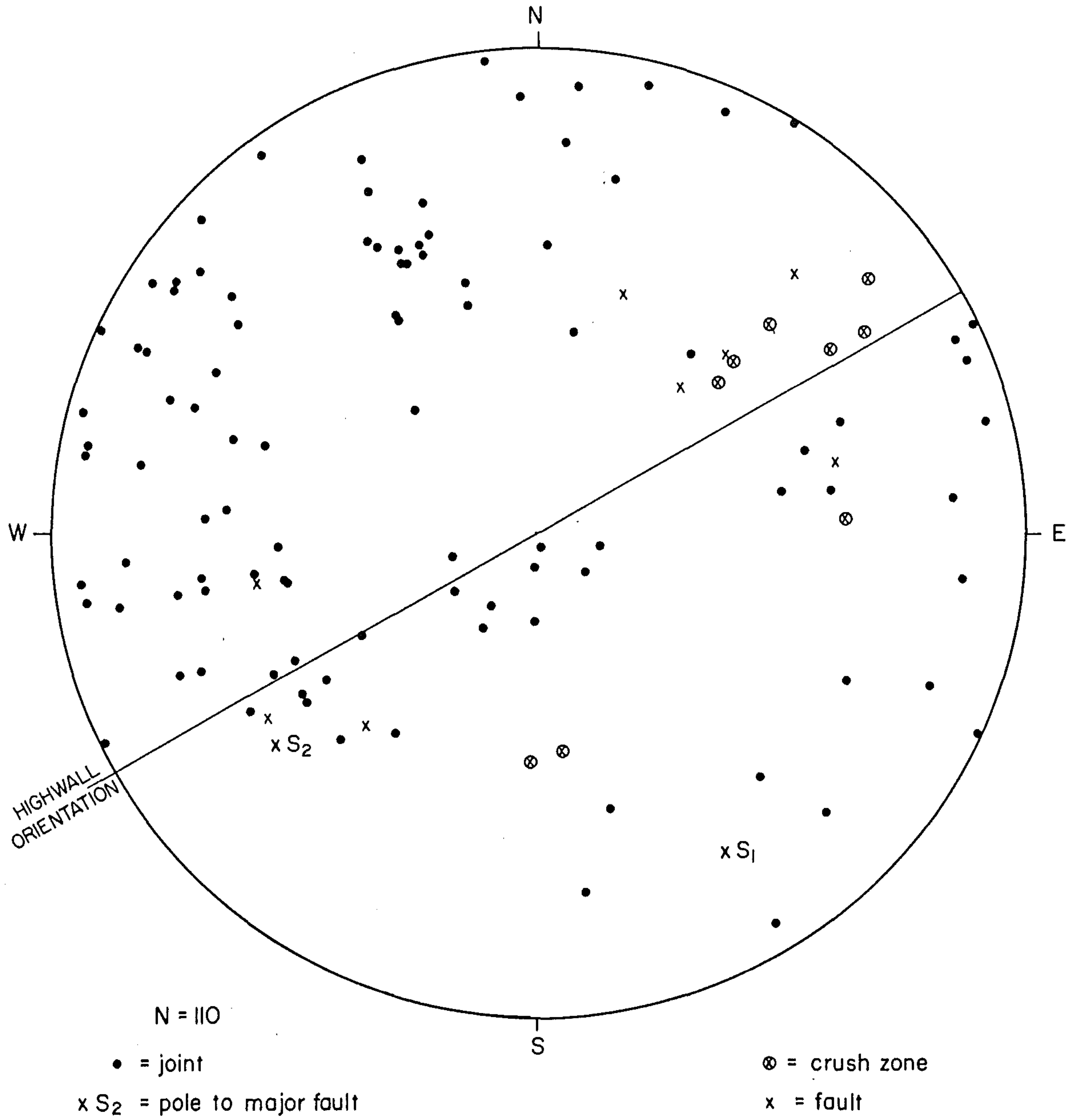


Figure A1·3

Weavers Opencast Mine
Defect Survey

FORMATION: WHANGAMARINO.
LOCATION: 623535 mN – 333555 mE / 623510 mN – 333570 mE
TAPE BEARING: 338° – 158°
DATE: JULY 1987.
R.L. +1·0 M
TAPE INCLINATION: HORZ.

STATION (M)	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS VR	R	SR	Sm	SL	FRACTURE SEPERATION (MM) <.1	.1-1	1-5	>5	GOUGE THICK.(cm)	CONT.(M)	WATER CONDITION DRY	MOIST	REMARKS $i = 1° - 2°$ for all defects.
0	joint	110	70	←5m±→			✓				✓			–			✓	Survey Line (A)
2.50	"	160	76	←4m±→				✓		✓				–			✓	"
3.28	"	132	80	←4m±→			✓			✓				–			✓	"
3.20	"	073	85	←6m±→			✓				✓			–			✓	"
4.70	"	131	85	←4m±→			✓			✓				–			✓	"
5.90	"	146	80	←4m±→			✓			✓				–			✓	"
7.01	"	303	87	←4m±→			✓			✓				–			✓	"
8.40	"	144	85	←3m→			✓			✓				–			✓	"
8.80	"	311	90	←3m→			✓			✓				–			✓	"
9.65	"	145	80	←3.5m→			✓			✓				–			✓	"
10.45	"	308	90	←4m→			✓			✓				–			✓	"
11.10	"	128	84	←4m→			✓			✓				–			✓	"
11.70	"	132	89	←2m→			✓			✓				–			✓	"
12.15	"	313	84	←4m→			✓			✓				–			✓	"
13.00	"	311	90	←4m→			✓			✓				–			✓	"
12.90	"	254	85	←8m→			✓			✓				–			✓	"
14.85	"	148	89	←4m→			✓			✓				–			✓	"

Weavers Opencast Mine
Defect Survey

FORMATION:
DATE:
LOCATION:
R.L.
TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
17.00	joint	154	86	←4m→			✓			✓				–		–	✓	Survey Line (A) contd.
18.20	"	330	82	←4m→			✓			✓				–		–	✓	"
19.50	"	155	85	←2m→			✓			✓				–		–	✓	"
20.25	"	138	89	←4m→			✓			✓				–			✓	"
20.50	"	144	80	←4m→			✓			✓				–			✓	"
22.40	"	162	70	←4m→			✓			✓				–			✓	"
23.60	"	338	80	←4m→			✓			✓				–			✓	"
24.10	"	144	85	←4m→			✓			✓				–			✓	"
24.70	"	150	86	←4m→			✓			✓				–			✓	"
25.40	"	152	84	←4m→			✓			✓				–			✓	"
26.30	"	155	89	←4m→			✓			✓				–			✓	"
26.80	"	334	89	←3m→			✓			✓				–			✓	"
27.20	"	326	81	←4m→			✓			✓				–			✓	"
28.40	"	151	88	←3m→			✓			✓				–			✓	"
29.60	"	154	89	←3m→			✓			✓				–			✓	"
30.00	"	091	80	←5m→			✓			✓				–			✓	"
0 – 30.00	bedding plane defect.	074	02	30m+			✓				✓			–			✓	"
	"	080	04	"			✓				✓			–			✓	"

333556 mE 623552 mN

Weavers Opencast Mine FORMATION: WHANGAMARINO LOCATION: 333550 mE 623522 mN TAPE BEARING: 004 – 184.

Defect Survey DATE: JULY 1987 R.L. –3M TAPE INCLINATION: HORZ.

STATION (M)	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
0.10	joint.	051	78	1m			✓			✓				–			✓	Survey Line B i = 1° – 2°.
2.40	"	052	76	1m			✓			✓				–			✓	"
3.65	"	147	85	0.6m			✓			✓				–			✓	"
4.70	"	051	75	0.2m			✓			✓				–			✓	"
6.50	"	025	75	0.2m			✓			✓				–			✓	"
7.13	"	054	81	0.2m			✓			✓				–			✓	"
9.00	"	050	87	0.15m			✓			✓				–			✓	"
9.60	"	052	90	0.21m			✓			✓				–			✓	"
9.92	"	174	81	0.51m			✓			✓				–			✓	"
10.60	"	071	83	0.52m			✓			✓				–			✓	"
13.25	"	055	75	0.20m			✓			✓				–			✓	"
13.52	"	182	88	0.15m			✓			✓				–			✓	"
14.20	"	150	88	0.60m			✓			✓				–			✓	"
16.70	"	082	86	1.00			✓			✓				–			✓	"

Weavers Opencast Mine
Defect Survey

FORMATION: WHANGAMARINO
LOCATION: 333533 mE 623548mN
333542 mE 623529mN
TAPE BEARING: 338° - 158°
DATE: JULY 1987.
R.L. -4M
TAPE INCLINATION: HORIZ.

STATION (M)	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
0.0	joint.	030	75	←1m→			✓				✓			–			✓	SURVEY LINE C i = 1°-2° for
0.70	"	190	73	←1m→			✓				✓			–			✓	" all defects.
–	"	209	85	←1m→			✓				✓			–			✓	"
1.30	"	212	84	←1.5m→			✓				✓			–			✓	"
3.15	"	150	89	←1.0m→			✓				✓			–			✓	"
3.50	"	148	88	←1.0m→			✓				✓			–			✓	"
3.95	"	155	90	←1.0m→			✓				✓			–			✓	"
4.15	"	030	86	←3.0m→			✓				✓			–			✓	"
6.20	"	192	75	←1.50m→			✓				✓			–			✓	"
6.00	"	125	76	←1.0m→			✓				✓			–			✓	"
7.30	"	160	70	←1.0m→			✓				✓			–			✓	"
7.85	"	165	85	←0.80m→			✓				✓			–			✓	"
9.80	"	158	88	←0.70m→			✓				✓			–			✓	"
10.30	"	067	90	←6.50m→			✓				✓			–			✓	"
11.10	"	344	85	←1.50m→			✓				✓			–			✓	"
12.50	"	150	82	←1.0m→			✓				✓			–			✓	"
13.50	"	160	88	←1.0m→			✓				✓			–			✓	"

Weavers Opencast Mine
Defect Survey

FORMATION:
DATE:
LOCATION:
R.L.
TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
14.00	joint	336	85	⊢ 1.0 →			✓				✓			–			✓	Survey Line © contd.
15.10	"	348	75	⊢ 0.5 →			✓				✓			–			✓	"
16.40	"	158	90	⊢ 1.0 →			✓				✓			–			✓	"
20.00	"	027	85	⊢ 3.0 →			✓				✓			–			✓	"

Weavers Opencast Mine
Defect Survey

FORMATION: WHANGAMARINO LOCATION: 333530mE 623530mN / 333523mE 623565mN TAPE BEARING: 344 - 164
DATE: JULY 1987. R.L. -6m. TAPE INCLINATION: HORZ.

STATION (M)	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS VR	R	SR	Sm	Sl	FRACTURE SEPERATION (MM) <.1	.1-1	1-5	>5	GOUGE THICK (cm)	CONT (M)	WATER CONDITION DRY	MOIST	REMARKS
1.0	joint.	358	70	8m			✓							–			✓	Survey Line D. $i = 1° - 2°$
2.30	"	355	55	8m			✓							–			✓	"
3.40	"	007	85	8m			✓							–			✓	"
4.50	"	002	74	10m			✓							–			✓	"
5.30	"	355	65	8m			✓							–			✓	"
5.95	"	004	66	8m			✓							–			✓	"
7.20	"	009	80	8m			✓							–			✓	"
8.80	"	001	58	8m			✓							–			✓	"
10.25	"	001	55	10m			✓							–			✓	"
10.95	"	001	58	11m			✓							–			✓	"
11.70	"	001	60	9m			✓							–			✓	"
12.30	"	006	72	8m			✓							–			✓	"
13.30	"	006	85	8m			✓							–			✓	"
13.80	"	005	66	9m			✓							–			✓	"
14.80	"	330	50	8m			✓							–			✓	"
15.10	"	328	50	8m			✓							–			✓	"
15.25	"	331	58	3m			✓							–			✓	"

Weavers Opencast Mine
Defect Survey

FORMATION:
DATE:
LOCATION:
R.L.
TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
15·45	joint	326	55	8			✓							–			✓	Survey Line D contd.
16·70	"	358	61	5			✓							–			✓	"
17·20	"	336	60	4			✓							–			✓	"
17·90	"	331	62	3			✓							–			✓	"

Weavers Opencast Mine
Defect Survey

FORMATION: WHANGAMARINO LOCATION: 333 425 mE 623525 mN (above it: 333 385 mE 623520 mN) TAPE BEARING:
DATE: July 1987. R.L. -10 M TAPE INCLINATION: HORZ.

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
	joint.	170	75	←20m→			✓				✓			–			✓	Survey Line E i = 1° – 2°.
	"	356	85	←20m→			✓					✓		–			✓	"
	"	351	86	←20m→			✓					✓		–			✓	"
	"	173	87	←7m→			✓			✓				–			✓	"
	"	173	90	←20m→			✓			✓				–			✓	"
	"	170	89	←20m→			✓			✓				–			✓	"
	"	248	80	←2m→			✓				✓			–			✓	"
	"	160	75	←4m→			✓				✓			–			✓	"
	"	165	85	←3m→			✓				✓			–			✓	"
	"	170	80	←2m→			✓				✓			–			✓	"
	"	161	89	←1m→			✓				✓			–			✓	"
	"																✓	

Weavers Opencast Mine
Defect Survey

FORMATION: GLEN AFTON.   LOCATION: TAPE BEARING: 225° – 45°

DATE: JULY 1987   R.L. -13 M.   TAPE INCLINATION: HORZ.

STATION (M)	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
0 – 2.5	joint.	110	65	2.5				✓			✓			–		✓		SURVEY LINE F
6 – 11.0	"	154	53	5				✓			✓			–		✓		
10.0	"	101	85	·2				✓			✓			–		✓		all joints are dry but iron stained.
14.5	"	084	86	1			✓			✓				–		✓		
14 – 19.5	"	151	58	5.5			✓				✓			–		✓		
14.8	"	276	77	3			✓				✓			–		✓		
15.0	"	185	82	2			✓							–		✓		
21 – 23.8	"	158	55	28				✓						–		✓		
24 – 30	"	161	62	6			✓							–		✓		
23.8	"	067	65	1.5			✓				✓			–		✓		
25.0	"	068	89	2				✓			✓			–		✓		
26.0	"	080	78	1.5			✓				✓			–		✓		
32.0	"	086	75	4			✓				✓			–		✓		
34.0	"	174	89	2			✓			✓				–		✓		
37.5 – 40	"	154	46	2.5				✓						–		✓		
41.0	"	154	53	1				✓						–		✓		
41.0	"	204	85	1				✓		✓				–		✓		

Weavers Opencast Mine
Defect Survey

FORMATION:
DATE:
LOCATION:
R.L.
TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS VR	R	SR	Sm	SL	FRACTURE SEPERATION (MM) <.1	.1-1	1-5	>5	GOUGE THICK (cm)	CONT (M)	WATER CONDITION DRY	MOIST	REMARKS
43.0	joint.	250	56	2			✓						✓	1-2.5		✓		Survey Line (F) contd.
41.0	"	248	85	1			✓			✓				–		✓		

Bedding plane shear, continuous in outcrop over 40m, aperature size variable (tight to 1cm) in width
Gouge infilling present over distances of 30m; gouge consists of moist plastic green grey clay.
Shear plane is planar over its distance, its surfaces are smooth i angle = 0°
Relative position stratigraphically is approximately 3m above WCM/GAC contact.
Average dip direction of shear plane is into the batter face, with readings at:

(i) 008°/6° at 9m from SW end of outcrop
(ii) 345/2° " 14m " " " " "
(iii) 284/10° " 25m " " " " "
(iv) 310/10° " 36m " " " " "

Weavers Opencast Mine
Defect Survey

FORMATION: GLEN AFTON
DATE: JULY 1987.

LOCATION: 333853 mE 623165 mN
333881 mE 623189 mN
R.L. -10 M

TAPE BEARING: 220° – 40°
TAPE INCLINATION: HORZ.

STATION (M)	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
2.40	joint.	082	50	⊢ 0.5 →			✓							–		✓		Survey Line 6
2.70	"	087	45	⊢ 0.5 →			✓							–		✓		"
1.60 - 3.10	"	318	58	⊢ 1.6 ⊣			✓							–		✓		" all joints dry but
4.20	"	110	70	⊢ 0.5 →			✓							–		✓		" iron stained.
6.50	"	105	88	⊢ 1.0 →			✓							–		✓		"
6.50	"	154	68	⊢ 0.9 →			✓							–		✓		"
8.10	"	340	70	⊢ 0.6 →			✓							–		✓		"
6.90	"	092	59	⊢ 0.5 →			✓							–		✓		"
11.10 - 12.80	"	125	65	⊢ 1.70 ⊣			✓							–		✓		"
11.10	"	292	76	⊢ 1.30 ⊣			✓							–		✓		"
11.20	"	245	85	⊢ 0.5 →			✓							–		✓		"
12.00	"	115	90	⊢ 0.8 →			✓							–		✓		"
14.30 - 18.00	"	128	78	⊢ 3.70 →			✓							–		✓		"
17.70	"	107	56	⊢ 1.20 →			✓							–		✓		"
18.10	"	123	85	⊢ 1.80 →			✓							–		✓		"
20.2 - 21.5	"	128	69	⊢ 1.50 →			✓							–		✓		"
22.3	"	124	80	⊢ 1.20 →			✓							–		✓		"

Weavers Opencast Mine
Defect Survey

FORMATION:

LOCATION:

TAPE BEARING:

DATE:

R.L.

TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS VR	R	SR	Sm	Sl	FRACTURE SEPERATION (MM) <.1	.1-1	1-5	>5	GOUGE THICK (cm)	CONT (M)	WATER CONDITION DRY	MOIST	REMARKS
23.6	joint	081	85	⊢1.4→			✓							–		✓		Survey Line G contd.
21.0	"	124	80	⊢2.5→			✓							–		✓		"
26.9	"	315	72	⊢1.0→			✓							–		✓		"
30.0	"	115	81	⊢2M→				✓						–		✓		"
28.9	"	296	60	⊢0.6→			✓							–		✓		"
27.6	"	115	79	⊢2.0→			✓							–		✓		"
35.0	"	094	55	⊢0.5→			✓							–		✓		"
34.8	"	100	85	⊢0.6→			✓							–		✓		"
38.0	"	108	50	⊢0.8→			✓							–		✓		"
38.1	"	256	85	⊢0.7→			✓							–		✓		"

Weavers Opencast Mine
Defect Survey

FORMATION: GLEN AFTON
DATE: JULY 86

LOCATION: 333868 mE 623210 mN
332928 mE 623267 mN
R.L. -9 M

TAPE BEARING: 220° - 40°
TAPE INCLINATION: HORZ.

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M) base top	ROUGHNESS VR	R	SR	Sm	SL	FRACTURE SEPERATION (MM) <.1	.1-1	1-5	>5	GOUGE THICK.(cm)	CONT.(M)	WATER CONDITION DRY	MOIST	REMARKS
29.0	small fault	226	45	←3→				✓				✓		0.5–1			✓	
34.0	shear	232	75	←3→			✓					✓		0.2–0.5			✓	
37.8	joint.	329	85	←4→				✓			✓			–			✓	
39.6	"	133	85	←4→				✓			✓			–			✓	
40.5	"	144	87	←4→				✓			✓			–			✓	
41.0	crush zone	228	45	←4→			✓				✓			.05–.1			✓	
42.10	shear	228	54	←4→			✓					✓		.1–.2			✓	
58.00	crush zone	354	38	←6-7→			✓					✓		.3–.4			✓	
49.30	minor crush zone	238	68	←5→			✓					✓		.1–.3			✓	
64.00	x joint	190	35	←3→				✓			✓			–			✓	
71.00	"	058	60	←4→				✓			✓			–			✓	} small wedge failure
71.00	"	158	53	←4→				✓			✓			–			✓	}
73.00	"	267	53	←3-4→			✓					✓		.1–.3			✓	
77.00	"	164	45	←2-3→				✓			✓			–			✓	
78.00	"	184	70	←2→				✓			✓			–			✓	
78.60	"	178	80	←2→				✓			✓			–			✓	

Weavers Opencast Mine
Defect Survey

332945mE 623284mN

FORMATION: GLEN AFTON. LOCATION: 332 977mE 623327mE TAPE BEARING: 220 – 40

DATE: JULY 86. R.L. –9M TAPE INCLINATION: HORZ.

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS survey line continued:
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
3.20	joint	260	42					✓			✓			–			✓	joints ironstained.
14.0	"	031	19				✓				✓			–			✓	
9.6	"	353	65				✓			✓				–			✓	
8.0	"	194	85				✓			✓				–			✓	
22.4	"	346	50					✓		✓				–			✓	
40.0	"	064	90				✓			✓				–			✓	} wedge failure.
43.0	"	163	41					✓			✓			–			✓	

Weavers Opencast Mine
Defect Survey

FORMATION: GLEN AFTON
DATE:

LOCATION: 332913 mE 623230 mN
332986 mE 623310 mN
R.L. -18m.

TAPE BEARING: 220°-40°.
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<·1	·1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
4.60	joint.	200	44	8				✓				✓					✓	Defect survey main G.A. batter.
11.20	"	035	43	7			✓			✓							✓	
12.50	"	135	30	4			✓			✓							✓	
12.50	"	055	55	4			✓			✓							✓	
28.00	"	078	44	8			✓			✓							✓	
12-28.00	"	117	64	4				✓		✓							✓	
37	"	061	53	8				✓		✓							✓	
40	"	062	48	5				✓		✓							✓	
44	"	155	75	4			✓				✓						✓	
65	"	080	65	6				✓			✓						✓	
65	"	253	48	–				✓			✓						✓	
69	fault.	055	58	–				✓				✓		0.4			✓	} wedge.
69	fault.	224	35	6				✓					✓	2.			✓	
75	"	147	45				✓				✓						✓	
130	fault.	225	64	6				✓					✓				✓	
130	jt.	100	73	6			✓				✓						✓	
61	"	147	44	8				✓		✓							✓	

Weavers Opencast Mine
Defect Survey

FORMATION: GAC
DATE July 1986
LOCATION:
R.L.
TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS VR	R	SR	Sm	Sl	FRACTURE SEPERATION (MM) <.1	.1-1	1-5	>5	GOUGE THICK (cm)	CONT (M)	WATER CONDITION DRY	MOIST	REMARKS
61	joint	220	40	5				✓		✓				–			✓	contin. of defect survey in main G.A.C batter.
61	"	082	60	5			✓			✓				–			✓	
-	"	080	65	6				✓			✓			–			✓	
-	"	265	75	5				✓			✓			–			✓	
Large	Papa Wedge Failure:																	
	NE Facing defect	055	45					✓									✓	
		053	50						✓								✓	slickensided fault surface.
		044	50					✓									✓	
	SW facing wall	160	56					✓									✓	
		192	64					✓									✓	
		182	50					✓									✓	
	platform.	130	10					✓									✓	

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: Feb. 1986

LOCATION:
R.L.

TAPE BEARING: 90 – 270.
TAPE INCLINATION: HORZ.

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK.(cm)	CONT.(M)	DRY	MOIST	
0	normal fault.	310	60	5m				✓			✓				5m	✓		only joints with continuity
0.5	joint	305	48	0.9		✓					✓				–	✓		of ≥1m measured.
0.6 – 1.74	bedding	005	3	1.10				✓			✓				–	✓		
2.90	shear	294	90	1.0		✓									–	✓		
3.10	joint	100	45	1.4		✓						✓			–	✓		
4.05	"	145	55	1.0				✓				✓						
0m.	Tape bearing	= 290 – 110			length = 8.0m.													
0.92	joint	075	60	1.0				✓			✓			0.1		✓		infilled by weathered sand and silt.
1.45	"	041	90	2.0				✓				✓				✓		
1.90	"	057	85	1.70				✓					✓			✓		partly infilled by loose rock fragments.
1.00 – 1.80	bedding plane	255	05	1.00				✓			✓					✓		
1.00	joint.	150	90	2.00			✓				✓					✓		
2.60	bedding	320	10	1.0				✓		✓						✓		
2.60 – 3.40	"	130	10	0.8			✓				✓					✓		
3.60	joint	085	65	1.0			✓			✓						✓		
5.40	shear	150	35	15.0				✓				✓		4mm			✓	

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: Feb. 1986

LOCATION:
R.L.

TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
0m	Tape bearing		225° —	45°.														
1.86	fracture	085	70	1.0				✓			✓			–		✓		
2.50	"	185	85	0.8				✓		✓				–		✓		
3.13	joint	280	60	3.0				✓		✓				–		✓		
3.70	"	276	84	0.8				✓		✓				–		✓		
6.47	"	085	45	1.07				✓										
6.60-7.60	bedding	290	05	1.00					✓	✓				–		✓		
8.97	normal fault.	088	60	3.00			✓			✓				–		✓		infilling crushed grit and rock.
0m.	Tape Bearing		290° —	110°														
0.33	joint.	086	66	1m				✓		✓				–		✓		
0.60	"	270	90	0.8				✓			✓			–		✓		
1.04	"	300	70	0.9				✓		✓				–		✓		
1.04	"	335	70	0.9				✓		✓				–		✓		
2.00	"	055	72	1.10				✓		✓				–		✓		

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: Feb 1986

LOCATION:
R.L.

TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
0.3	joint	358	85	0.9				✓		✓				–		✓		New Survey Line: 200° - 020° = Tape bearing.
0.58	"	155	90	1.5				✓		✓				–		✓		
0.98	"	265	80	2.0				✓					✓	–		✓		infilled with rocks, chips and sand.
2.84	"	200	85	2.1				✓		✓				–		✓		
3.52	"	135	85	1.5				✓		✓				–		✓		
4.75	"	075	85	3.0				✓		✓				–		✓		} shallow wedge failure in face.
5.0-6.0	"	122	85	1.0				✓				✓		–		✓		
6.0	"	160	90	0.9				✓			✓			–		✓		
6.38	"	135	80	1.2				✓		✓				–		✓		
6.46	"	076	90	0.8				✓		✓				–		✓		
6.80	"	190	87	0.8				✓		✓				–		✓		
6.98	"	040	85	1.10				✓		✓				–		✓		
7.18	"	205	85	1.0				✓			✓			–		✓		
7.75	"	230	75	0.8				✓				✓		–		✓		
7.30	"	088	77	0.9				✓		✓				–		✓		
7.66	"	085	60	1.0				✓		✓				–		✓		
8.90	"	073	72	3.0				✓		✓				–		✓		

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: Feb. 86

LOCATION:
R.L.

TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (CM)	CONT (M)	DRY	MOIST	
9.00	joint.	085	80	3m.				✓		✓				–		✓		
9.51	"	206	80	0.9			✓				✓			–		✓		
9.77.	"	230	85	2.0				✓			✓			–		✓		
10.10	"	234	85	1.2			✓			✓				–		✓		
10.30	"	230	80	1.2			✓			✓				–		✓		
10.70	"	030	85	1.3				✓			✓			–		✓		
11.63	"	085	85	1.5				✓		✓				–		✓		
6–25	bedding plane defect.	317	4.5°	30				✓					✓	0.05–0.10			✓	gouge = gritty silt. ~ bedding plane shear
–	"	344	05	12			✓						✓	0.7		✓		
6.40	"	103	77	-														
6.60	"	180	87	-														
	Survey Line,	Tape	bearing. 220°-40°.															
0m.	bedding plane defect.	300	05	16					✓	✓				–			✓	} same defect.
13m	"	262	05	16m					✓	✓				–			✓	
2.4	joint	073	85	1.0				✓		✓				–			✓	

Weavers Opencast Mine Defect Survey	FORMATION: WCM	LOCATION:	TAPE BEARING:
	DATE: Feb. 1986.	R.L.	TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIRN	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK.(cm)	CONT.(M)	DRY	MOIST	
3.0	joint.	090	87	1.0m		✓				✓				—			✓	
4.3	"	178	80	1.3m			✓			✓				—			✓	
0–30m	joint along bedding plane under hardbar.	300	12	30m+			✓				✓					✓		
5.2	joint.	081	85	1.0			✓				✓			—		✓		
7.12	"	084	87	1.0				✓		✓				-			✓	
11.1	shear	078	43	7.0		✓				✓				0.05cm		✓		moist, clayey silt, stiff.
11.5	joint	224	85	1.2			✓			✓				—		✓		
12.1	"	075	75	0.2				✓		✓				—			✓	
12.5	"	148	75	0.9				✓		✓				—			✓	
13.7	"	016	75	0.8				✓		✓				—			✓	
11.4	"	105	75	0.9				✓						—			✓	
14.0	"	252	85	0.95				✓				✓		-		✓		
14.35	"	065	90	1.80			✓				✓					✓		
13.9	"	150	75	0.9			✓				✓			-		✓		
14.35	"	065	90	1.80			✓					✓		-		✓		
16.70	"	093	66	1.0			✓			✓				-		✓		
22.0	"	355	45	1.2				✓			✓			-		✓		

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: FEB 1986

LOCATION:
R.L.

TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIR N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
20.5	joint.	087	74	0.80			✓				✓			–		✓		
24.8	"	062	49	0.90		✓				✓				–		✓		
25.0	small fault.	047	54	3 m.				✓		✓				–		✓		0.5m displacement, slickensided, no gouge infilling
28.0	"	058	35	1 M			✓			✓				1mm		✓		
29.0	"	076	60	1m				✓				✓		1-2mm			✓	6 joints subparallel to fault.
31.0	small. fault.	074	60	1.0			✓						✓	8½cm			✓	defect surfaces slickensided, 2m displacement.
0m.	Survey Line Orientation: 245°–065°.																	
0.54m	bedding plane contact fireclay/coal	245°	10°	←2.40→				✓		✓						✓		
5.75	joint	122°	85°	←1.20→				✓		✓				–		✓		
7.70	joint	130	85	←1.20→				✓		✓						✓		
7.89	"	310	45	0.9				✓		✓						✓		
9.08	"	123	85	1.3				✓		✓						✓		
11.03	"	122	60	0.8				✓		✓						✓		
12.20–12.78	"	200°	22°	1.09				✓		✓						✓		
14.20	"	116	70°	0.6			✓			✓						✓		
15.78	"	286	90°	0.9				✓		✓						✓		

142

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: FEB 1986.

LOCATION:
R.L.

TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	SL	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
15.94	joint	210	85	0.9				✓		✓				–		✓		
17.60	"	110	90	0.8				✓		✓						✓		
17.38	"	080	85	1.0				✓		✓						✓		
18.00	"	290	85	1.5				✓		✓						✓		
18.82	"	179	25	2.0				✓		✓						✓		
24.50	"	143	80	1.6				✓		✓						✓		
26.20	"	168	80	1.1				✓		✓						✓		
25.97	"	110	90	1.2				✓		✓						✓		
26.6	"	106	90	1.6				✓		✓						✓		
	fault.	104	45	20m.				✓					✓	30cm	20m.		✓	fault zone = 30cm wide, normal displacement of 5m.
	Fireclay underlying coal.	lenses of highly sheared very weak fireclay at contact base of Kupakupa seam.																
	New Survey Line 234°–54°																	
0	joint	120	60	1.8m			✓				✓			–				
1.20	"	171	85	1.0		✓					✓			–				
2.26	shear	070	71	6.0m			✓				✓			1mm		✓		gouge = crushed fireclay / 2cm displacement

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: FEB 1986

LOCATION:
R.L.

TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
	joint	347	85	0.9			✓					✓						
	"	124	65	1.2			✓					✓						
	"	257	70	4.0			✓				✓							
	"	153	81	4.5				✓			✓							
	"	261	50	3.1				✓			✓							
	"	269	48	3.0				✓			✓							
	"	262	55	3.0				✓			✓							
	shear	097	45	6.0			✓						✓					width = 5 m, fireclay crushed over 4m.
	joint	014	84	2.0				✓			✓							
	"	136	70	0.8			✓				✓							
	"	142	77	0.8			✓			✓								
	"	210	56	3.0			✓				✓							
	"	138	80	0.9				✓			✓							
	"	314	85	1.0			✓			✓								
	fault	327	75	7.0				✓				✓		0.5cm	7m.	✓		very weak fireclay + carbonaceous mudstone contains many slickensided surfaces (187/55). overlain by competent strong to moderately strong fireclay, but which contains numerous continuous shear joints.
	contact fireclay sheared/intact.	345	15	35.0		✓				✓				3mm			✓	
	shear.	261	70	4.0			✓				✓			2cm			✓	

142B

Weavers Opencast Mine
Defect Survey

FORMATION: WCM
DATE: FEB 1986.

LOCATION:
R.L.

TAPE BEARING:
TAPE INCLINATION:

STATION	DEFECT TYPE	DIP DIR.N	DIP ANGLE	CONTIN. (M)	ROUGHNESS					FRACTURE SEPERATION (MM)				GOUGE		WATER CONDITION		REMARKS
					VR	R	SR	Sm	Sl	<.1	.1-1	1-5	>5	THICK (cm)	CONT (M)	DRY	MOIST	
Survey Line Orient^n 220 – 40																		
0.0	joint	110	77	0.9														
3.0	Fault.	063	45	5m		✓							✓	25cm			✓	gouge = highly sheared + weathered fireclay. displacement = 3m.
7.0	joints.	122	50	0.90														
7.5	〃	315	85	1.64														
5.80	〃	060	50	2.50														
5.90	〃	068	50	3.0														
6.00	〃	065	45	3.0				joints subparallel to faulting.										
6.30	〃	065	55	1.0														
6.50	〃	065	45.	1.5														

142C

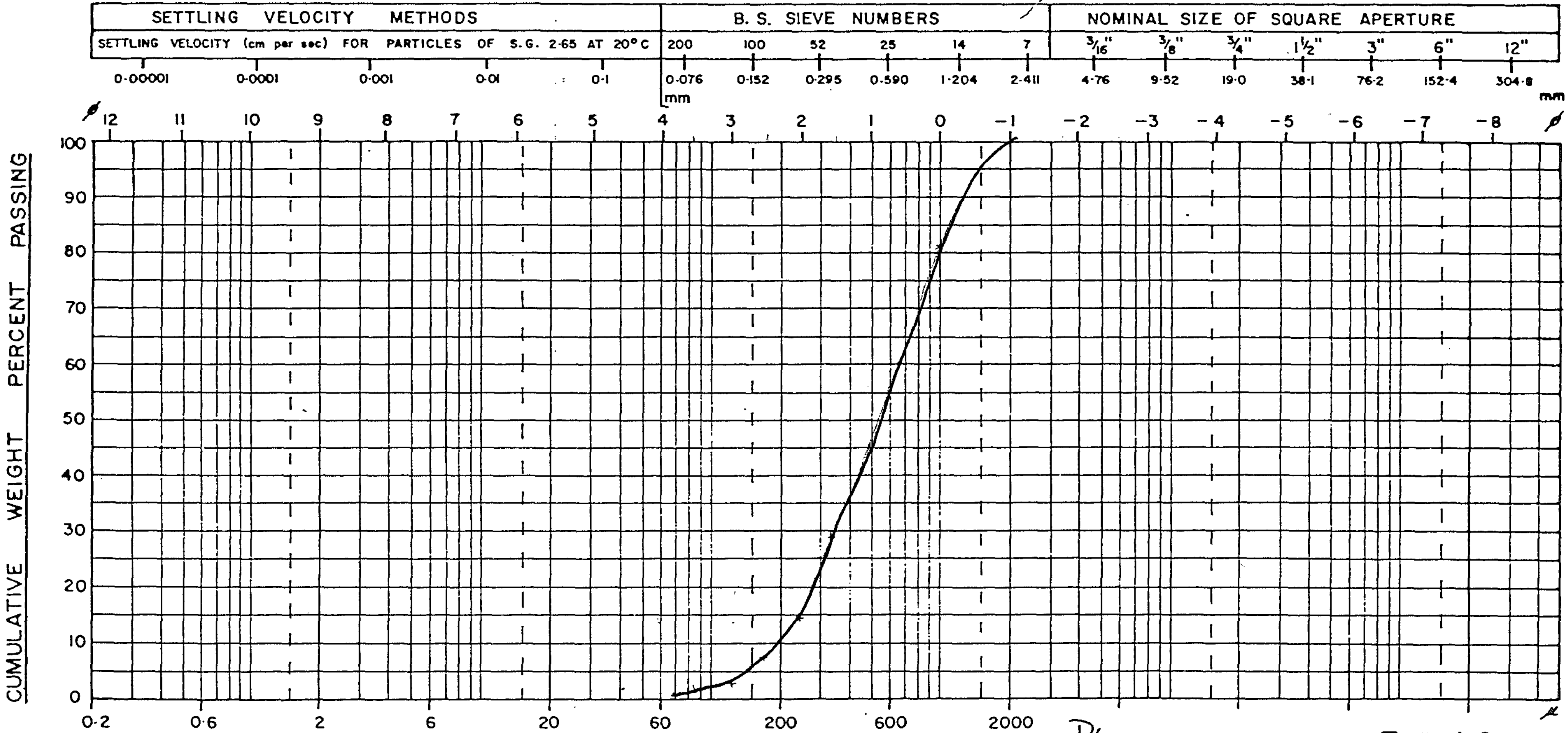
APPENDIX 2
GRAINSIZE DISTRIBUTION CURVES

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

A2·1

PROJECT ..Weavers Olc.......... SAMPLE NO ..4:80 M R.L..... SAMPLED BY ..U.W...... ANALYSED BY ..U.W......

..Batter Stability..... LOCATION .....BL 2.......... DATE .... DATE .Dec. 1986. .



$$\frac{D_{60}}{D_{10}} = 3$$

FIG. A2·1

mm 0·0002	0·0006	0·002	0·006	0·02	0·06	0·2	0·6	2	6	20	60	200 mm

← CLAY FRACTION	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	BOULDER FRACTION →
	SILT FRACTION			SAND FRACTION			GRAVEL FRACTION			

PARTICLE SIZE AND CLASSIFICATION.

A2·2

PARTICLE SIZE DISTRIBUTION – SEMI LOG PLOT

PROJECT ..Weavers Olc......... SAMPLE NO .5.5 M RL.......... SAMPLED BY ...U.W..... ANALYSED BY...U.W......

..Batter Stability..... LOCATION ....B.L. 2............ DATE .... DATE ..Dec..1986.

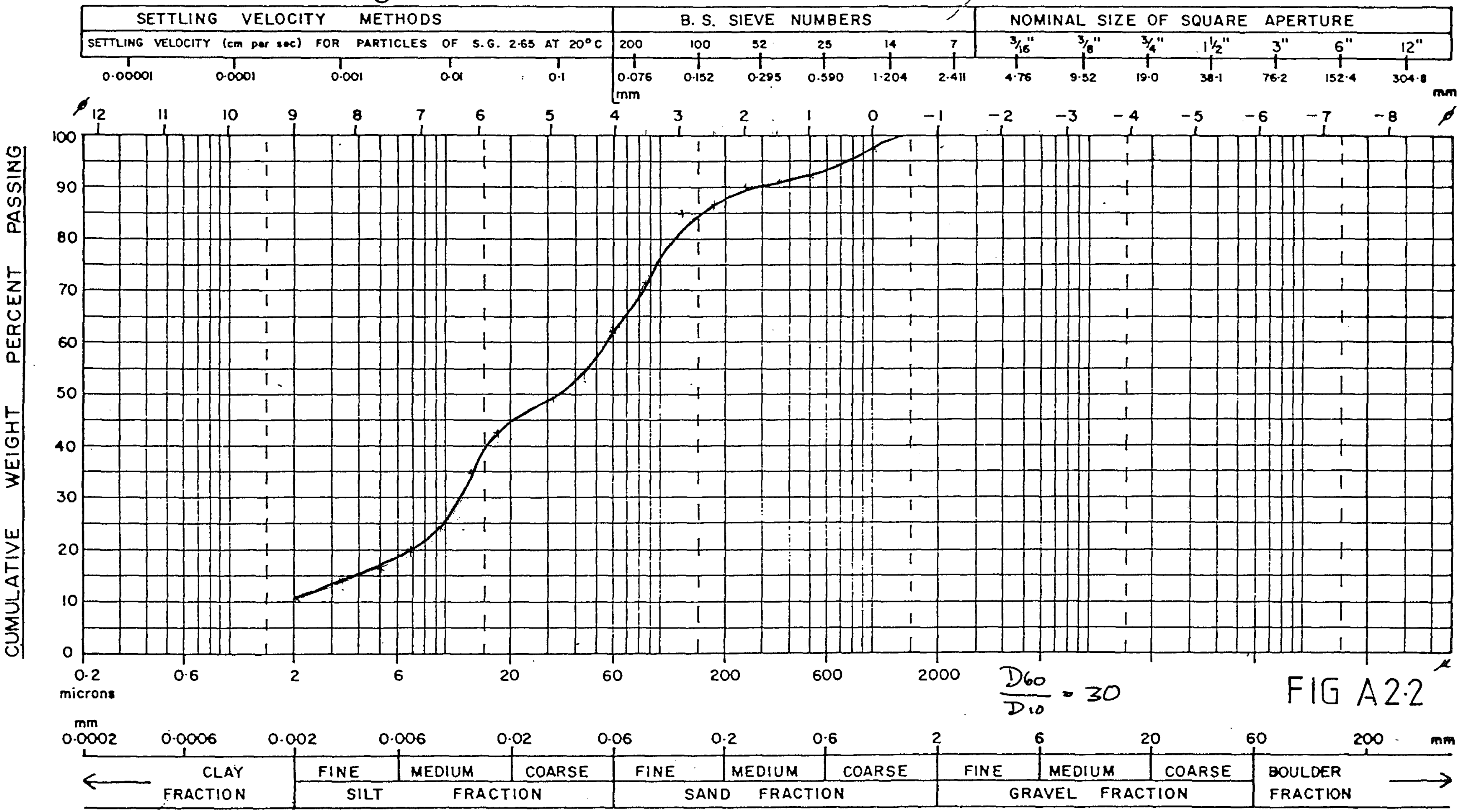


FIG A2·2

PARTICLE SIZE AND CLASSIFICATION

A 2·3

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

PROJECT Weavers O/c .... SAMPLE NO 6·0 m RL (aquitard) SAMPLED BY U.W. ...... ANALYSED BY U.W. ......

Batter Stability ...... LOCATION ... BL 2 .... DATE .... DATE Dec. 1986

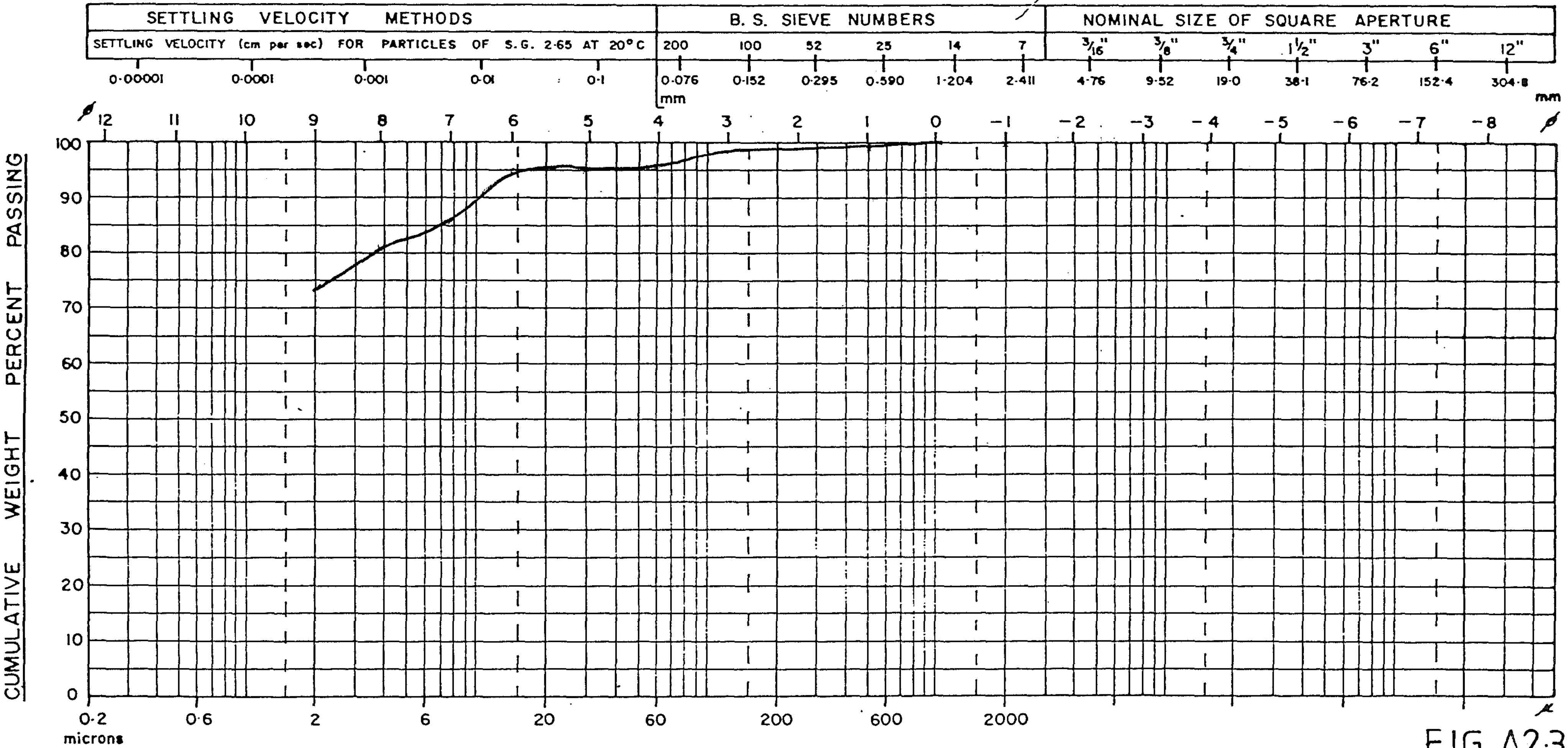


FIG A2·3

mm 0·0002	0·0006	0·002	0·006	0·02	0·06	0·2	0·6	2	6	20	60	200 mm

← CLAY FRACTION	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	BOULDER FRACTION →
	SILT FRACTION			SAND FRACTION			GRAVEL FRACTION			

PARTICLE SIZE AND CLASSIFICATION

A 2·4

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

PROJECT Weavers Olc SAMPLE NO −2·80 M RL SAMPLED BY u.w. ANALYSED BY u.w.
Batter Stability LOCATION BL 2 DATE .... DATE Dec. 1986

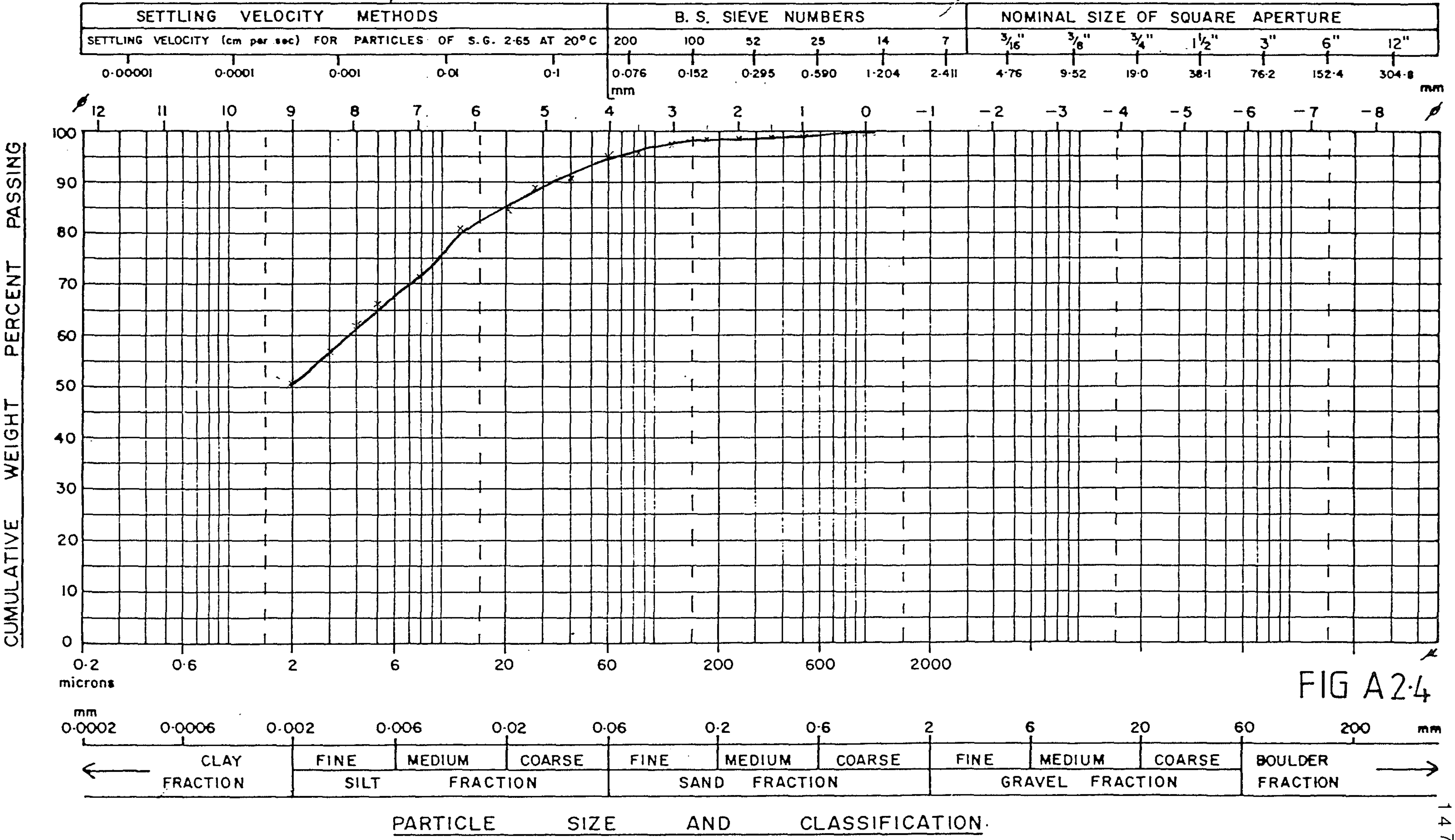


FIG A2·4

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT A2.5

PROJECT ..Weavers..O/c......... SAMPLE NO ...-4·20 M RL... SAMPLED BY ...U.W.... ANALYSED BY ..U.W.....

..Batter Stability... LOCATION ....BL 2......... DATE .... DATE .Dec. 1986. .

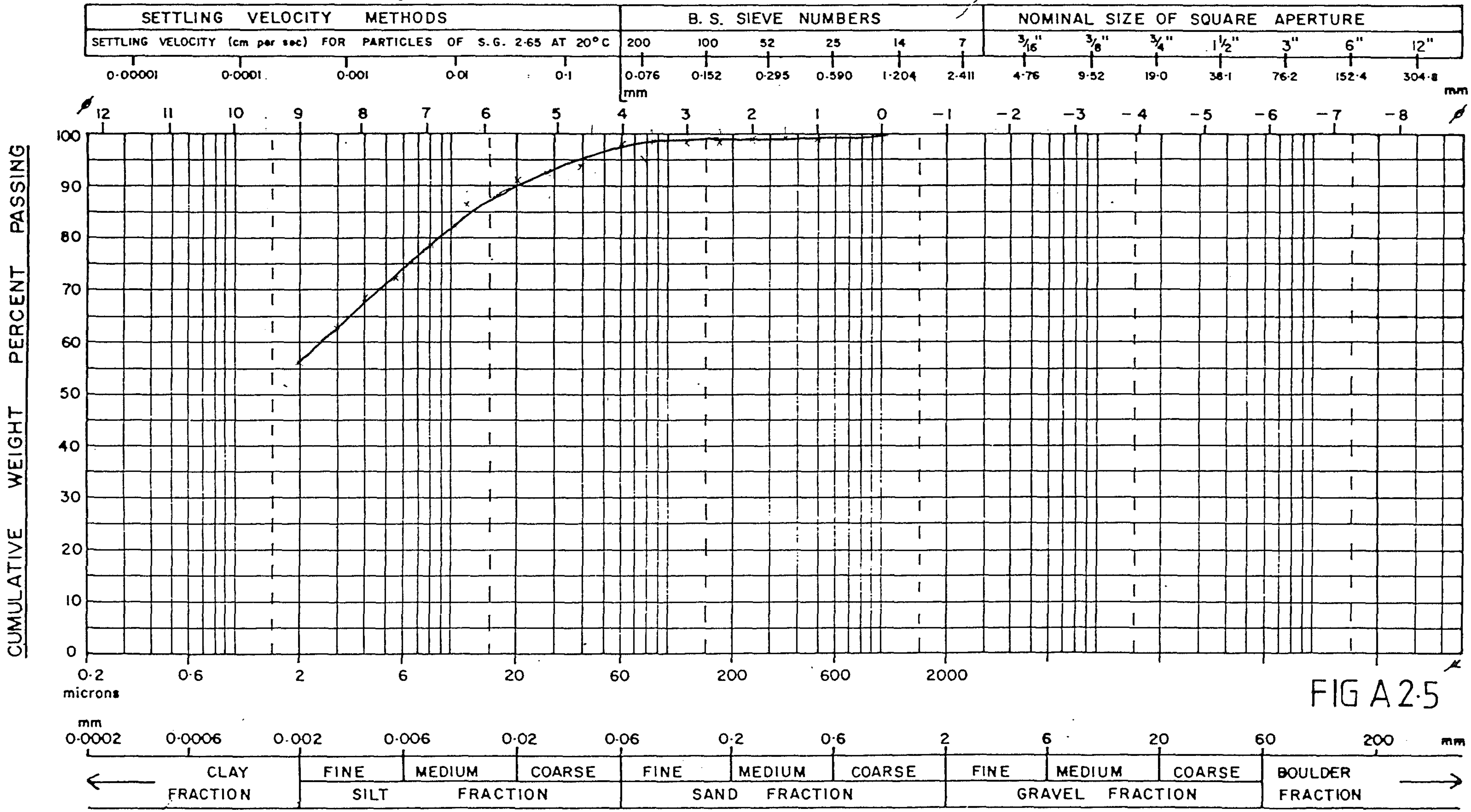


FIG A2·5

PARTICLE SIZE AND CLASSIFICATION

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT A2·6

PROJECT Weavers O/c. SAMPLE NO -250 m RL SAMPLED BY u.w. ANALYSED BY u.w.

Batter Stability LOCATION BL 2 DATE DATE Dec. 1986.

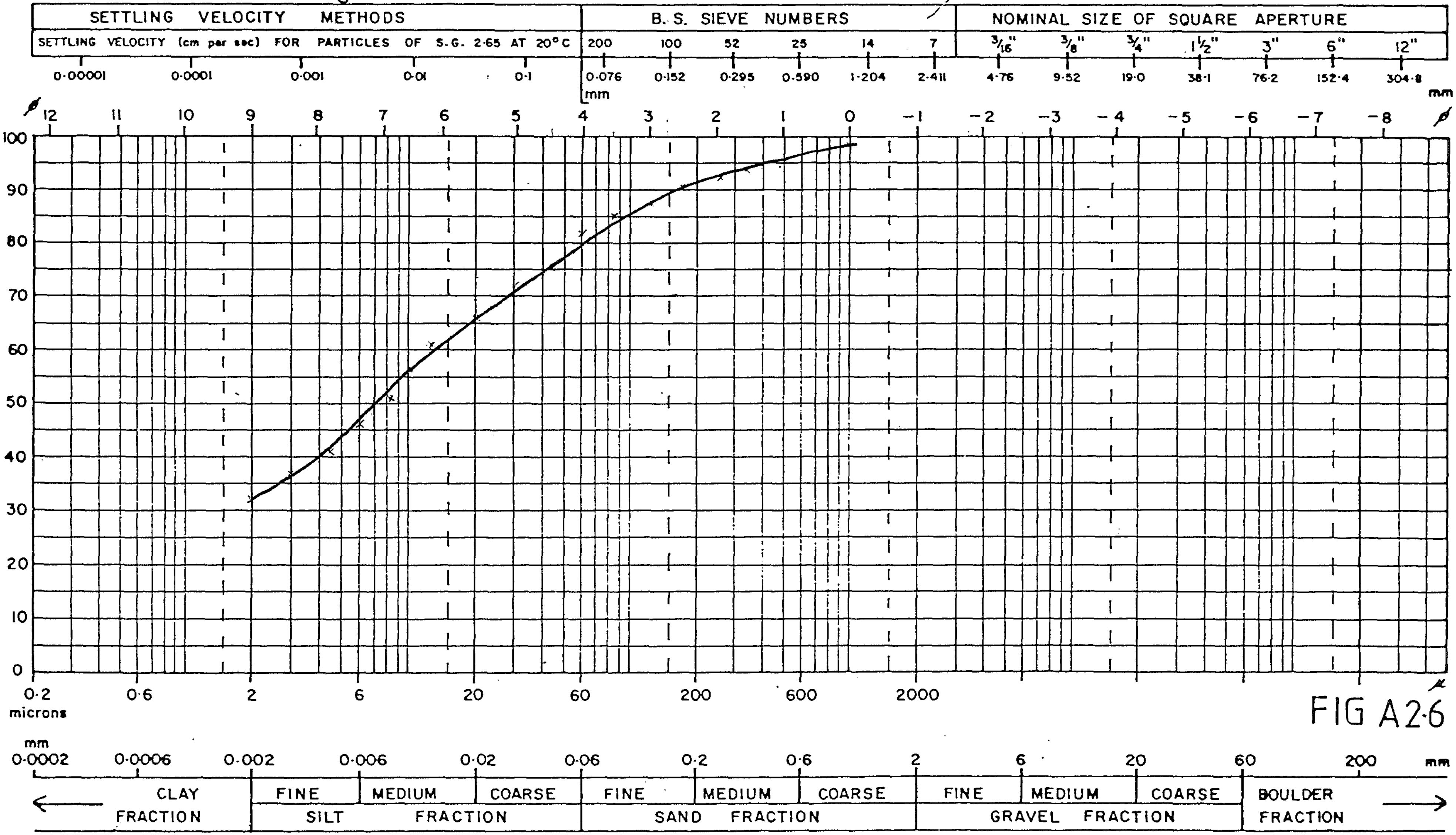


FIG A2·6

PARTICLE SIZE AND CLASSIFICATION

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT A'2.7

PROJECT Weavers O/c. SAMPLE NO -5-60 M RL SAMPLED BY U.W. ANALYSED BY U.W.

Batter Stability LOCATION BL 2? DATE DATE Dec. 1986

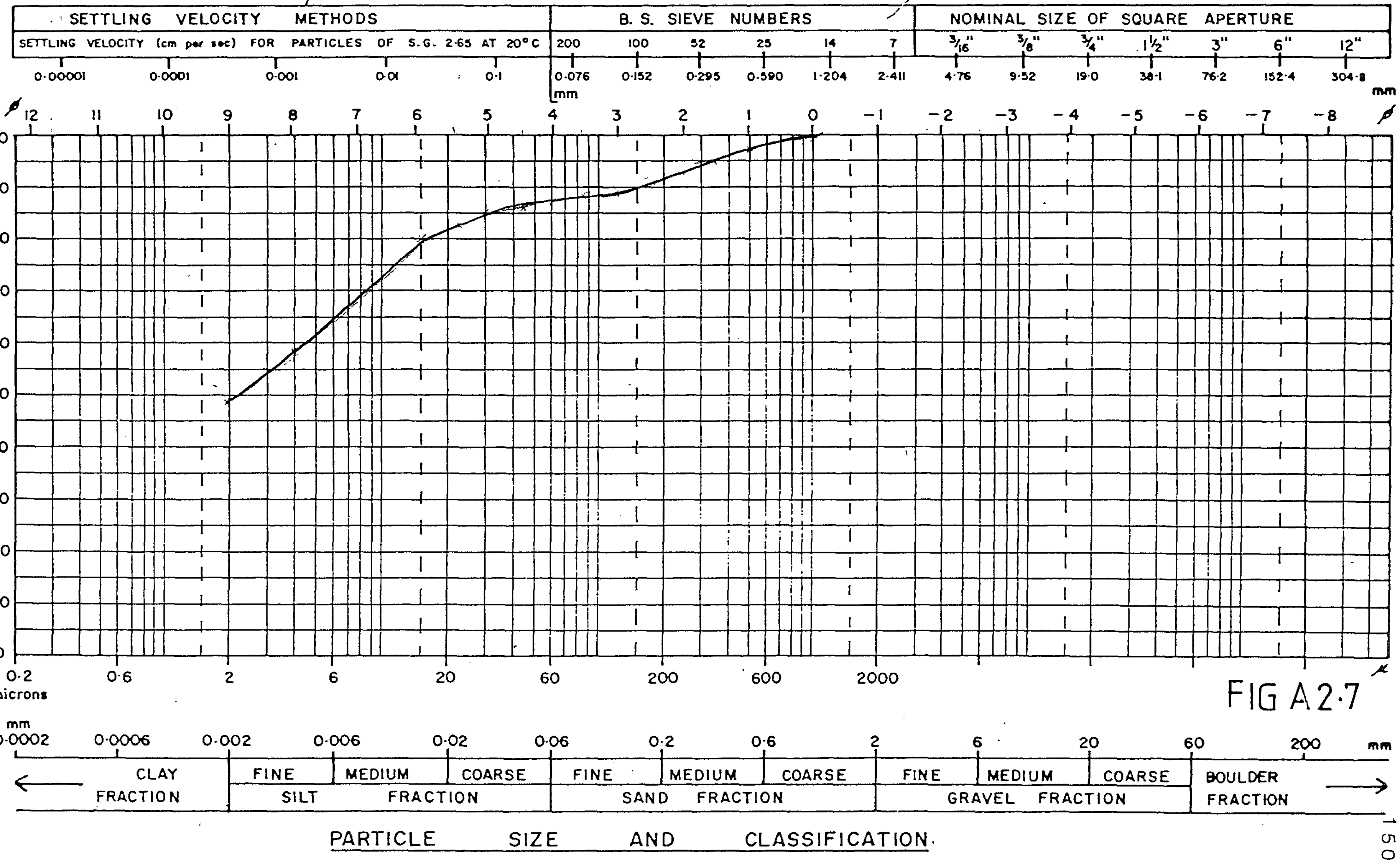


FIG A2.7

PARTICLE SIZE DISTRIBUTION – SEMI LOG PLOT

A2·8

PROJECT ..Weavers...Ok.......... SAMPLE NO ...-7·00 M. R.L. SAMPLED BY ...U.W.... ANALYSED BY ...U.W....

..Batter..Stability... LOCATION ......BL1........... DATE .... DATE ..Dec. 1986..

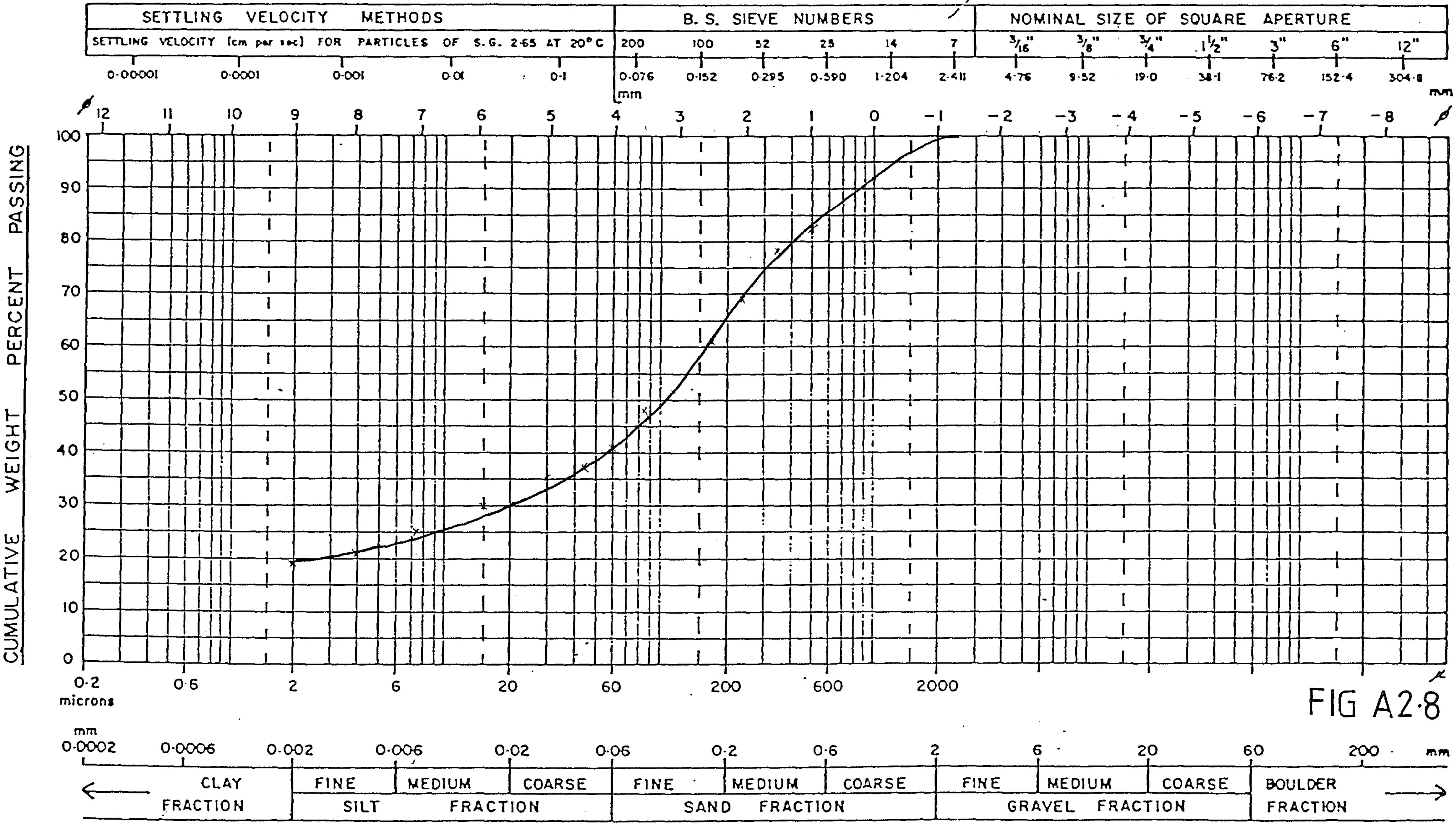


FIG A2·8

PARTICLE SIZE AND CLASSIFICATION.

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT A2·9

PROJECT Weavers o/c .... SAMPLE NO -10.5 M (RL) Lower Aquifer SAMPLED BY ... U.W ..... ANALYSED BY .. U.W ......

Batter stability .... LOCATION .... BL 1 .... DATE .... DATE Dec. 1986 ..

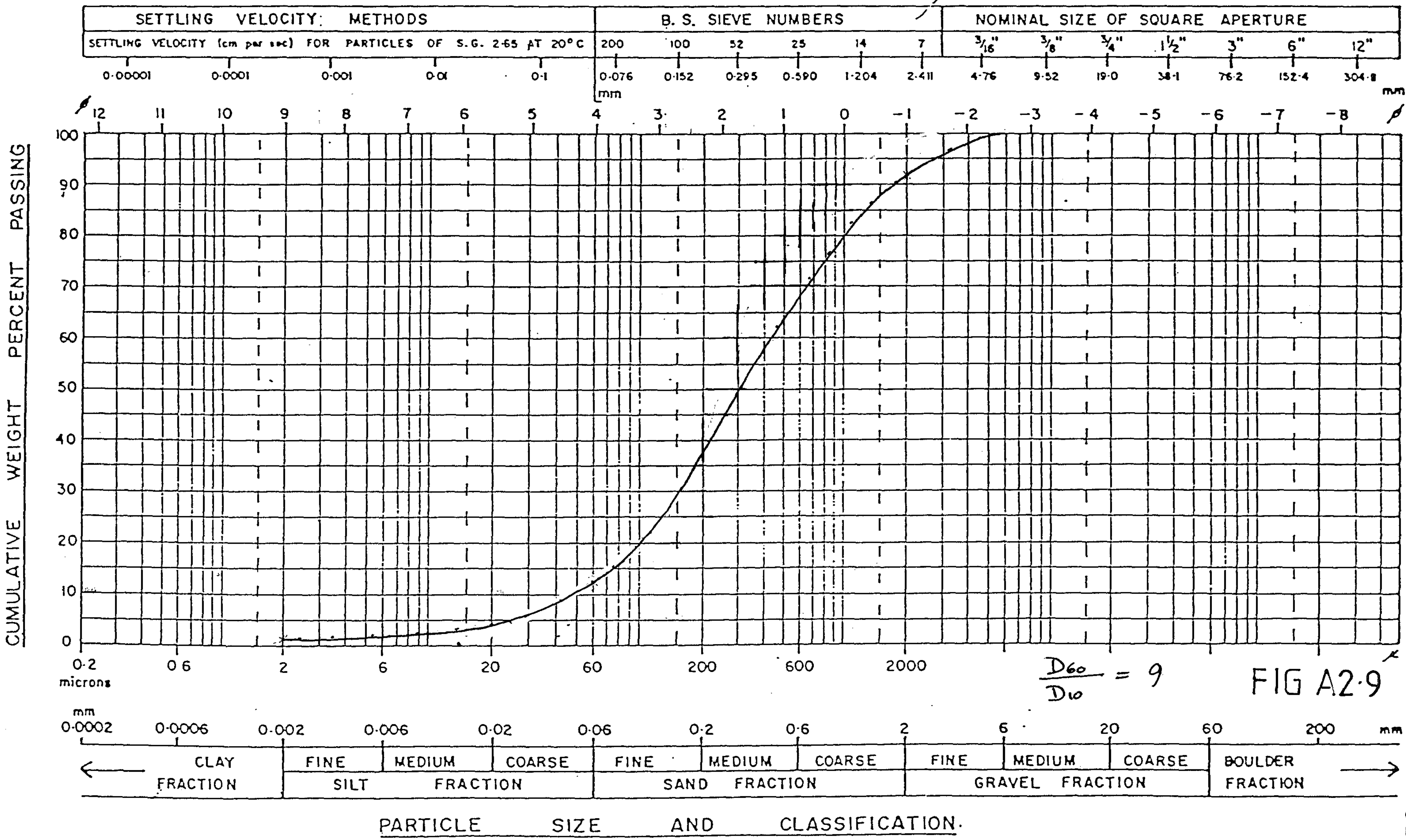


FIG A2·9

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PARTICLE SIZE DISTRIBUTION – SEMI LOG PLOT

A2·10

PROJECT ..WEAVERS..Q1c....... SAMPLE NO ..-1-O.M.RL..(H).. SAMPLED BY ....U.W.... ANALYSED BY...U.W.....

..BATTER..STABILITY.... LOCATION .....BL5.............. DATE .... DATE ..Dec..1986

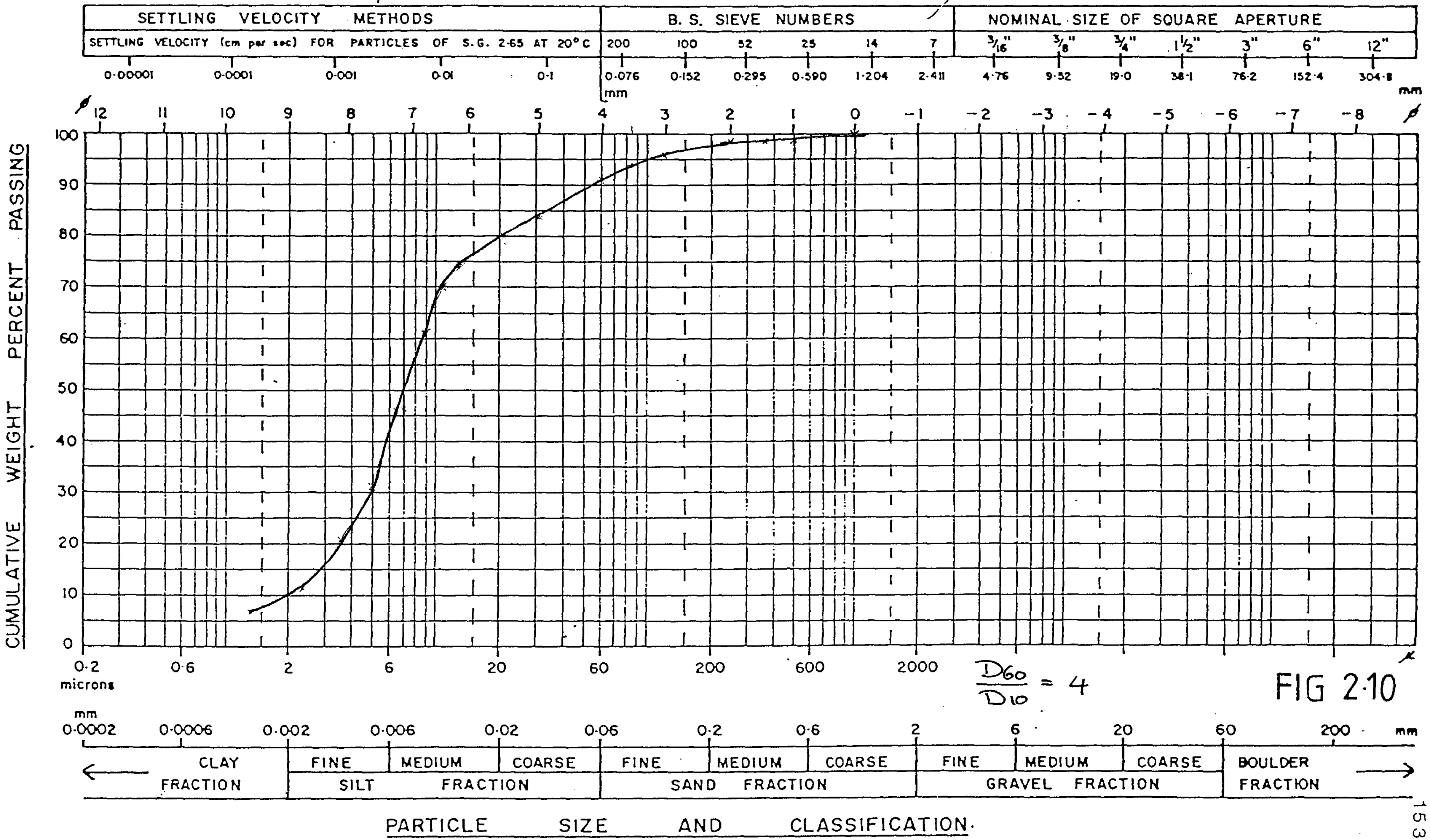


FIG 2·10

PARTICLE SIZE DISTRIBUTION – SEMI LOG PLOT A 2·11

PROJECT Weavers O/c SAMPLE NO -4.00 M R.L. (D) SAMPLED BY U.W. ANALYSED BY U.W.
Batter Stability LOCATION BL 5 DATE .... DATE Dec. 1986

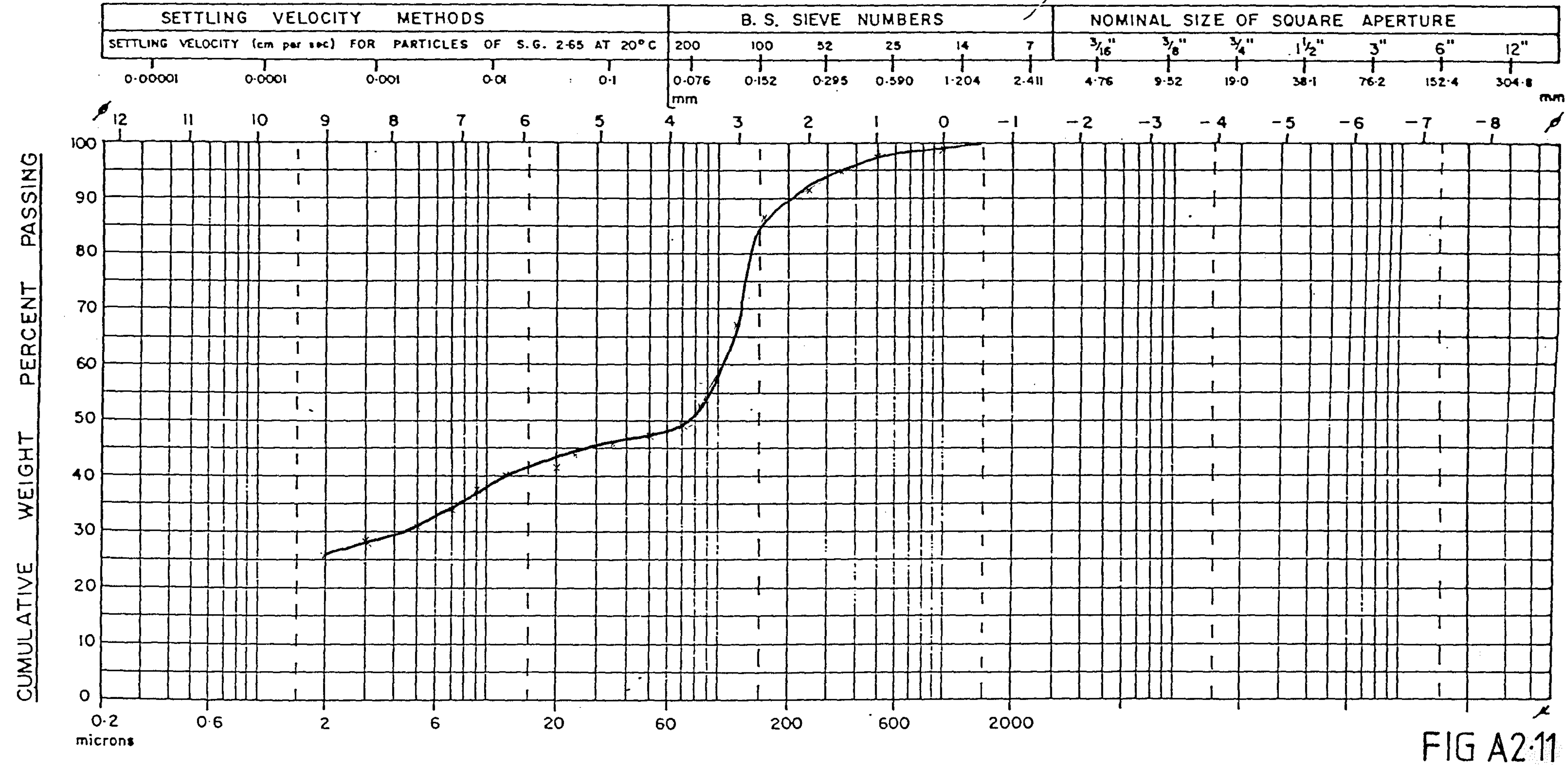


FIG A2·11

mm 0·0002	0·0006	0·002	0·006	0·02	0·06	0·2	0·6	2	6	20	60	200 mm
← CLAY FRACTION		FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	FINE	MEDIUM	COARSE	BOULDER FRACTION →	
		SILT FRACTION			SAND FRACTION			GRAVEL FRACTION				

PARTICLE SIZE AND CLASSIFICATION.

PARTICLE SIZE DISTRIBUTION – SEMI LOG PLOT A 2·12

PROJECT Weavers O/C: ...... SAMPLE NO -370M (RL) (C) SAMPLED BY ...U.W.... ANALYSED BY ..U.W.....

..Batter Stability.... LOCATION ....BL 5........... DATE .... DATE ..Dec. 1986.

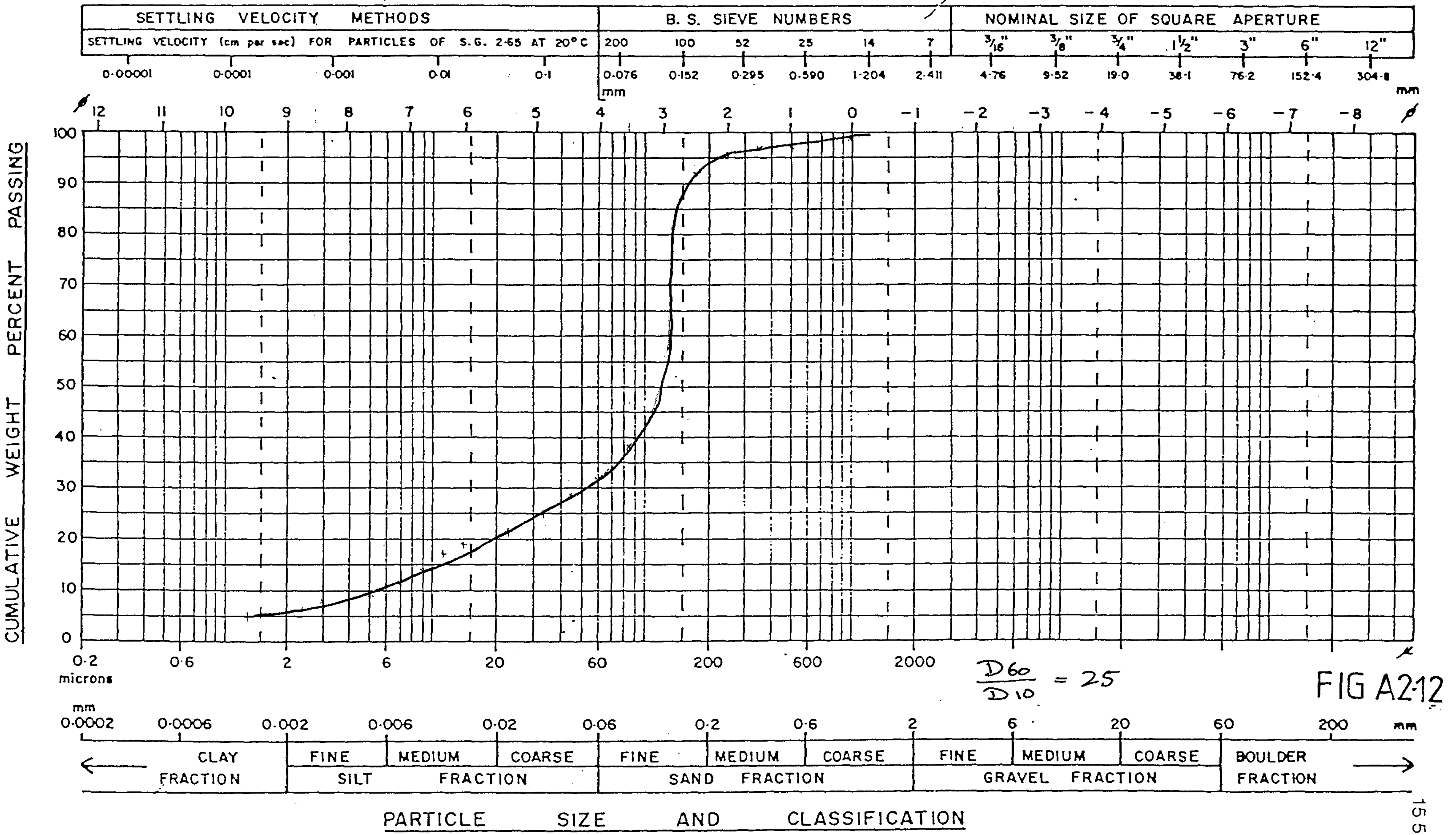


FIG A2·12

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT

A 2·13

PROJECT ...Weavers O/c......... SAMPLE NO ..-3·70 M RL (K) SAMPLED BY ....U·W.... ANALYSED BY ...U·W.....

...Batter Stability.. LOCATION .....BL 5............ DATE .... DATE .Dec. 1986.

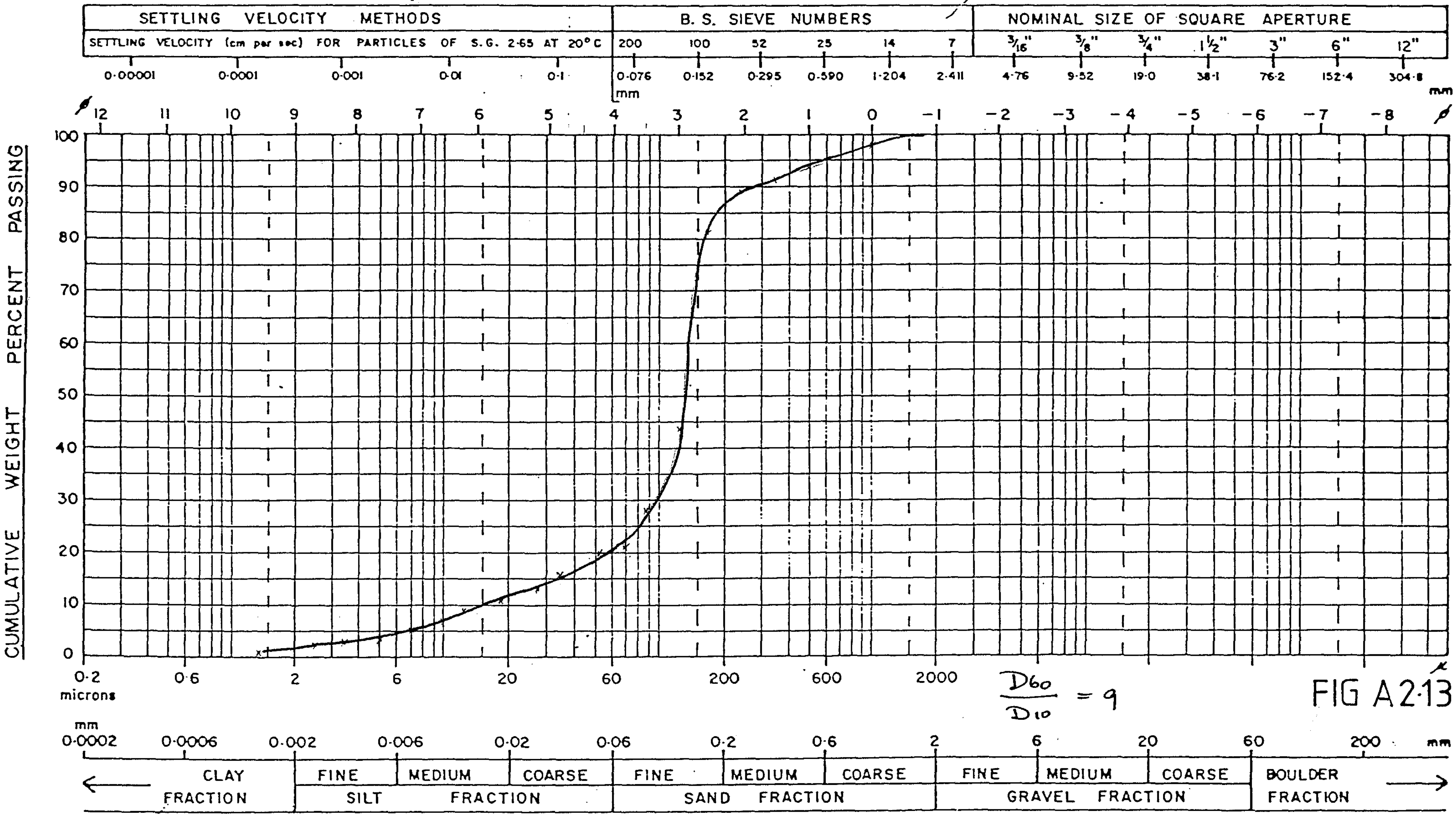


FIG A2·13

PARTICLE SIZE AND CLASSIFICATION

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT A 2·15

PROJECT ..WEAVERS..O/C.:....... SAMPLE NO ..-4·50 M. R.L...(F) SAMPLED BY ... U.W.... ANALYSED BY ...U:W.....
..BATTER..STABILITY.... LOCATION ....B.L.5........... DATE .... DATE ..Dec. 1986

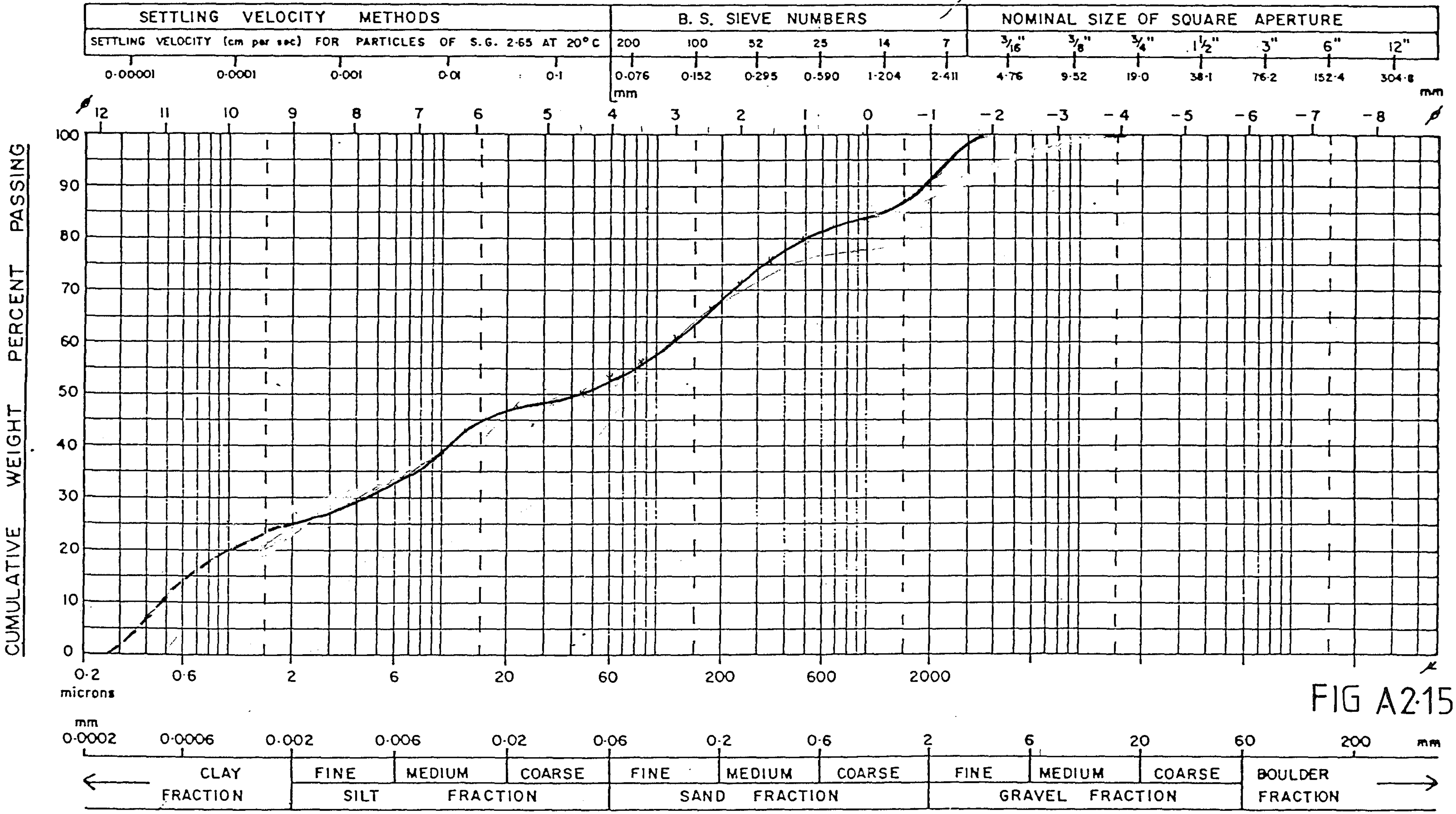
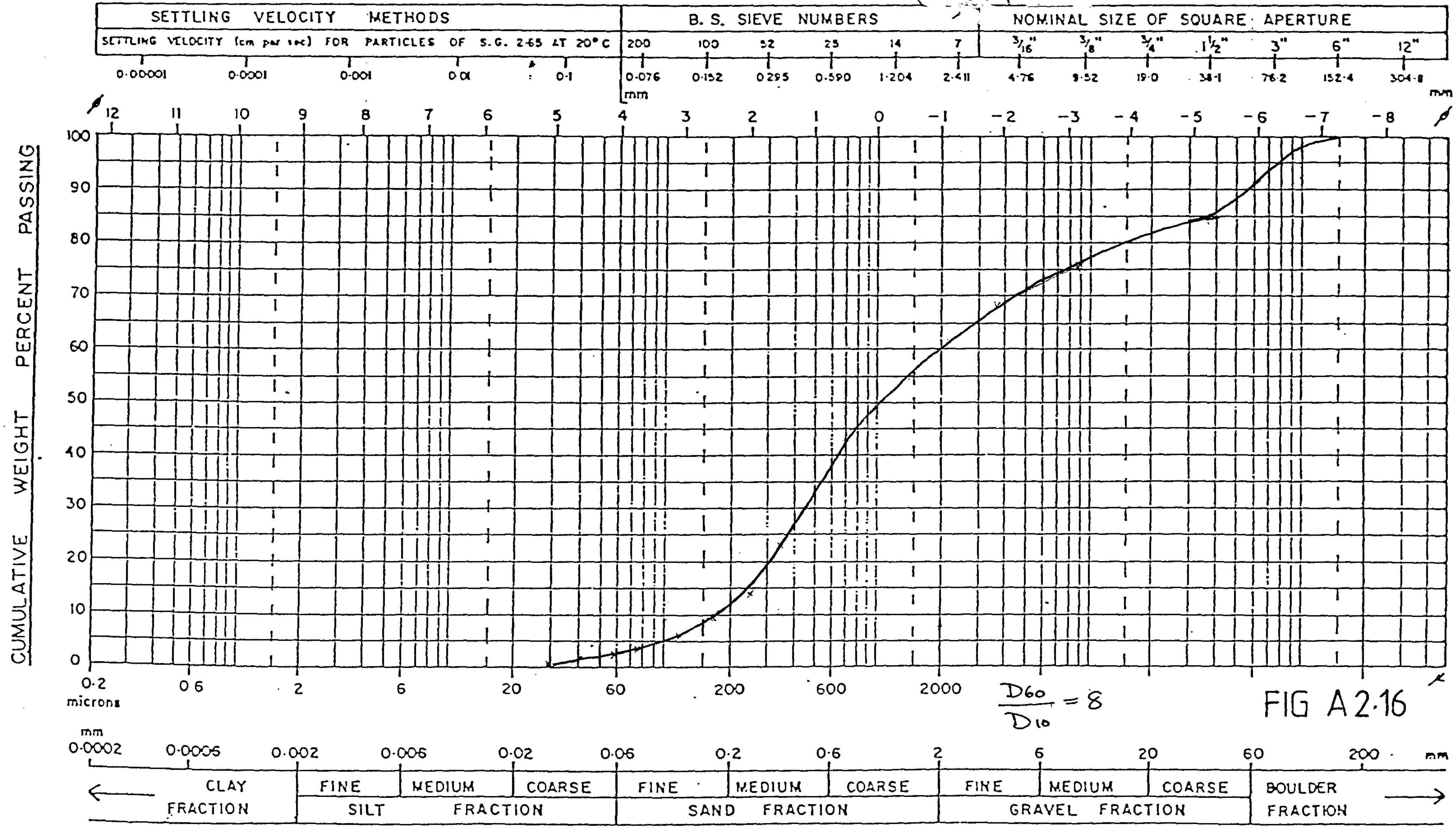


FIG A2·15

PARTICLE SIZE AND CLASSIFICATION.

PARTICLE SIZE DISTRIBUTION — SEMI LOG PLOT A2·16

PROJECT Weavers Olc .... SAMPLE NO Channel above Papa SAMPLED BY .. U.W. ..... ANALYSED BY .. U.W. .....
Batter Failure .... LOCATION Wedge Failure ..... DATE .... DATE Dec. 1986 ..



$\frac{D_{60}}{D_{10}} = 8$

FIG A2·16

PARTICLE SIZE AND CLASSIFICATION.

APPENDIX 3
ATTERBERG LIMIT DATA

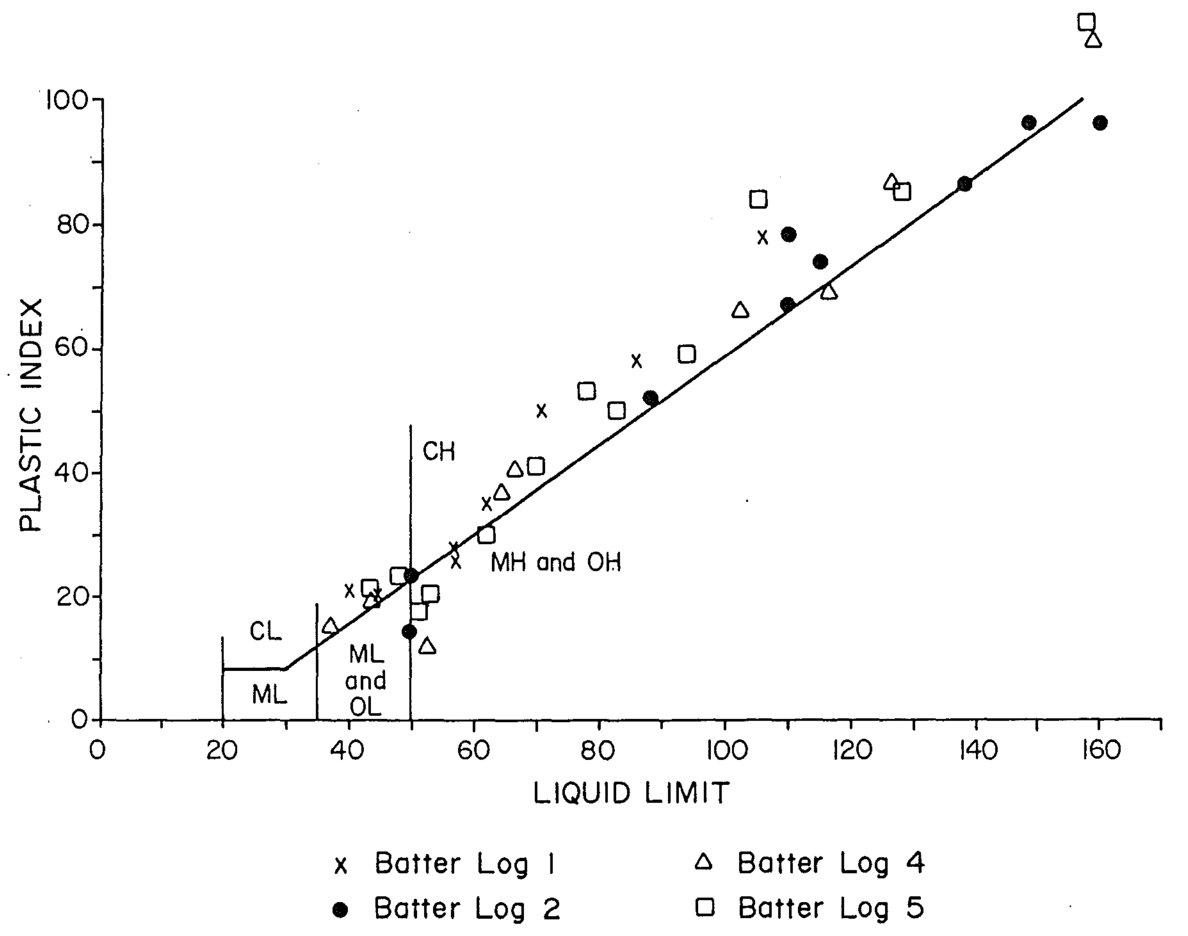


Figure A3·1 Atterberg limit data

APPENDIX 4
CLAY MINERALOGY and GRAINSIZE
of
STRENGTH SAMPLES

APPENDIX 4a

Preparation of Clay Mounts for Semiquantitative Clay Mineralogy

Semiquantitative clay analysis was carried out on the clay fractions of the ring shear sample, and the shearbox samples of the Whangamarino Silt.

Oriented mounts of clay fraction were prepared according to the method of Campbell (1975). The preparation steps include;

1) 25g (dry weight) of material were hand dispersed in distilled water. The suspension was subsequently further dispersed using an ultrasonic probe at medium intensity for 3 minutes.
2) Samples were then wet sifted to obtain the mud fraction (<63um), which was subsequently transferred to a 1000cc settling column. The sieve fraction still remaining was subjected to further cycles of wet sifting until all the mud fraction was obtained.
3) 25cc of 2% sodium hexametaphosphate were added to the mud fraction in the settling column, which was then thoroughly stirred and left for observation.

If flocculation was observed the mud fraction was transferred to the centrifuge for further treatment. The sample was centrifuged at 2000rpm for 10 minutes, after which the supernatant liquid was tipped off. The material was again rewashed with distilled water and thoroughly shaken before a further 10 minutes centrifuging. This process was continued until complete dispersion was observed by the cloudy appearance of the mud fraction in the sample tubes.

4) After complete dispersion is obtained the mud fraction is transferred back to the settling column, where a further 25cc of 2% calgon was added. The column was subsequently topped up with distilled water until the 1000cc level, after which it was thoroughly stirred and left.
5) After 24 hours the suspension was syphoned off at a depth of 30cm to obtain the clay fraction. The mud fraction left in the settling column was again topped up to the 1000cc level, stirred and left for another 24 hours, after which the clay fraction was again syphoned off. This procedure

was continued until the whole size range of the clay fraction was collected.

5) The clay fraction thus obtained was stored in a volumetric flask, and was subsequently flocculated out from the excess water using 20cc of $MgSO_4$ (molar).
6) The concentrated clay fraction was subsequently centrifuged and washed with distilled water to remove the magnesium sulphate and redisperse the sample (according to the procedure of step 3).
7) The final step was to bring the dispersed clay suspension to a standard concentration. The suspension was transferred to a volumetric flask of 100cc from which a 10cc withdrawal was made. The 10cc withdrawal was deposited into a beaker and weighted. The beaker plus suspension were subsequently placed under a heat lamp until the suspension was dry. The weight of the dry clay fraction was used to measure the concentration of clay per 10cc of suspension. On the basis of this calculation the remaining 90cc in the volumetric flask was further diluted or concentrated to achieve a suspension of 1% concentration of clay fraction.
8) The 1% suspension was thoroughly stirred, after which 2.25cc was withdrawn and transferred onto a glass slide. Care was taken not to disturb the clay suspension while it was drying, and to keep it out of direct sunlight.

APPENDIX 4b

Semiquantitative Clay Mineralogy:

Peak heights were determined on the diffractogram patterns of shear strength samples (II and III) and IV , by measuring peak height above a base line. Calculation of the relative abundances of clay minerals present were made using the procedure of Hume and Nelson (1982). This procedure was used in preference to others as it was developed with reference to soils from the South Auckland Region.

Calculations are based on the following assumptions:

1) The reported clay minerals are considered to comprise 100% of the sample, whereas in some samples there are other minerals present, as well as amorphous materials.
2) The refracting ability of the clay minerals of the same species, which is dependent on composition and degree of crystallinity, is considered to be constant.
3) The weighing corrections selected for individual clay mineral species are assumed to be valid.

The procedure is as follows:

1) On the XRD pattern of the untreated sample, the reflected base intensities of the 3.3Å (Illite) and 3.5Å (kaolinite) peaks are measured, and expressed as the ratio 3.5Å/3.3Å.
2) On the XRD trace of the glycolated sample the peak intensities at 10Å (illite), 18Å (smectite), 14Å (chlorite, vermiculite), 12Å (chlorite - illite mixed layer) and 11Å (illite -smectite mixed layer). To collect for low angle polarisation, the peak intensities are divided as follows: 17Å by 4, 14Å, 12Å -13Å, and 11Å by two. The corrected peak intensities are then divided by the 10Å peak intensity, summed along with the value for 3.5Å intensity / 3.3Å intensity obtained in (1), and recalculated to 100%.
3) On the diffraction pattern of the HCL treated sample the 10Å (illite) and 7Å (kaolinite) are measured, the 7Å peak then divided by two, and compared to the 10Å peak. This ratio is an expression of kaolinite in the chlorite plus chlorite percentage % value calculated in the last step of (2). Kaolinite is then calculated and chlorite % obtained by subtraction.

4) Total mixed layer percentage is obtained by summing the individual mixed layer percentages.

The results obtained are assumed to be accurate within 10%, and should be consistent within one study.

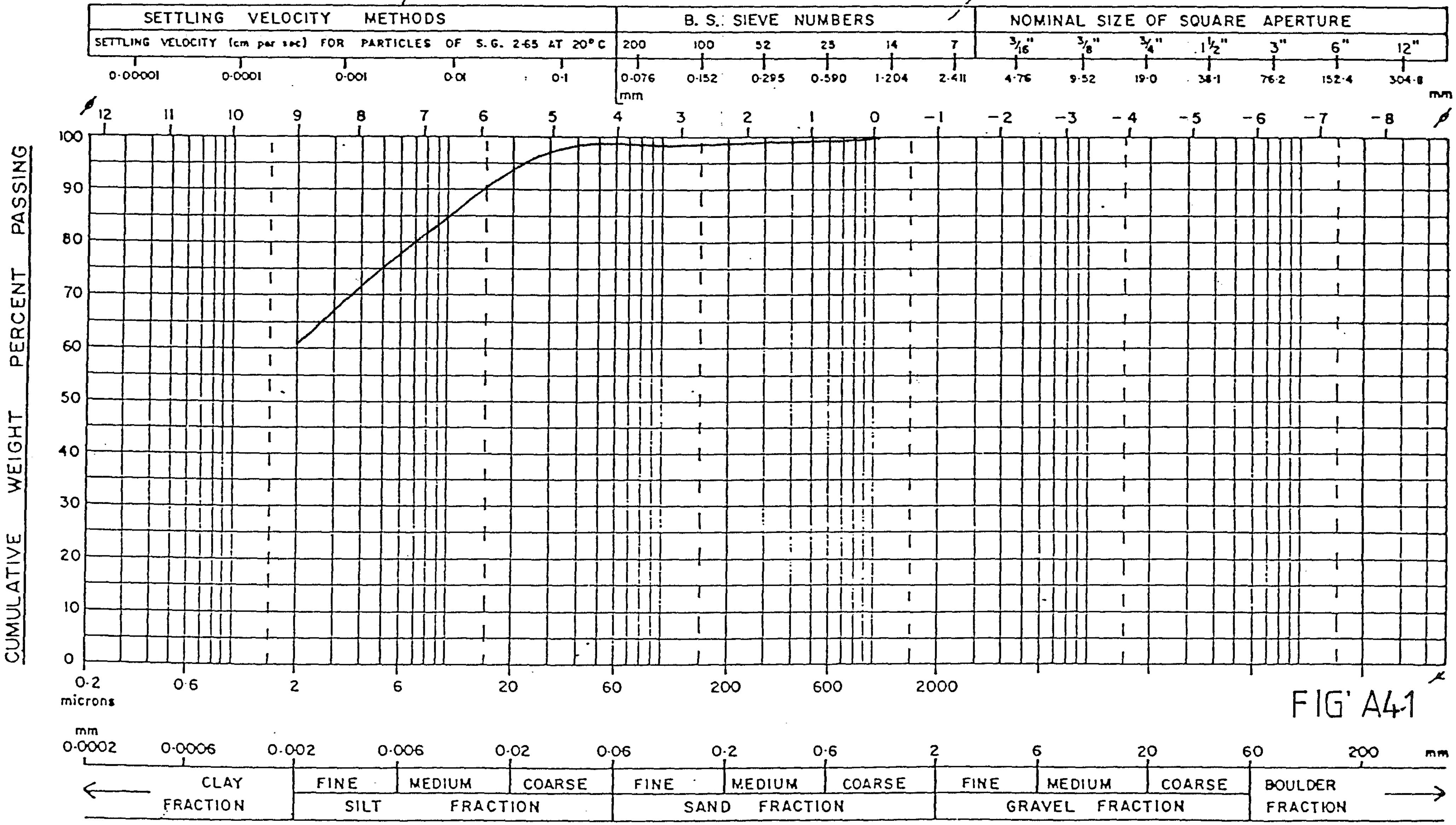
Figures A4.3 and A4.4 illustrate the major peaks on the diffractogram patterns of the samples tested. Illite can be recognised on the basis of its 10Å reflection, which remains unaffected by glycolation, heat and acid treatment. Smectite is recognised by a broad peak centring on 14Å, which expands to 18Å on glycolation and collapses to 10Å at 350°. Kaolinite can be recognised by the 7Å peak on the untreated sample, which remains unaltered after 10 minutes boiling in 10% HCL. Chlorite on the diffractograms of both samples was recognised by a decrease in the 7Å peak of the acid treated sample. The chlorite 14Å peak is overshadowed by the 14Å peaks of smectite and vermiculite. Vermiculite is identified on the diffractogram patterns of samples II and III as a sharp reflection at 14Å which remains unaffected by glycolation and heating at 300°C and 500°C, but collapsed at 700°C to 10Å. Two mixed layer clays were identified, at 11Å (possibly illite - smectite) which expands to 13Å on glycolation and collapses to 10Å on heating to 350°C. Another mixed layer clay at 12Å (possibly chlorite - illite) expands to 14Å on glycolation, and collapses back to 10Å upon heating to 500°C.

The following relative abundances were measured;

Samples II and III;		Sample IV;
kaolinite	20%	40%
chlorite	10%	20%
illite	50%	20%
vermiculite	10%	-
smectite	<10%	10%
I - C	<10%	<10%
I - S	-	<10%

PARTICLE SIZE DISTRIBUTION – SEMI LOG PLOT A4·1

PROJECT ..WEAVERS..OIC:...... SAMPLE NO 7MRL........... SAMPLED BY ...U·W..... ANALYSED BY ...U·W:....
...BATTER STABILITY... LOCATION ...BL5............ DATE RING SHEAR SAMPLE DATE ...Dec..1986



FIG' A4·1

PARTICLE SIZE AND CLASSIFICATION.

PARTICLE SIZE DISTRIBUTION - SEMI LOG PLOT A4·2

PROJECT Weavers O/c .... SAMPLE NO ......-9·50 M. R.L SAMPLED BY ....U.W.... ANALYSED BY...U.W...

..Batter Stability........ LOCATION ....B.L 1......... DATE SAMPLES II and III DATE Dec. 1986 ..

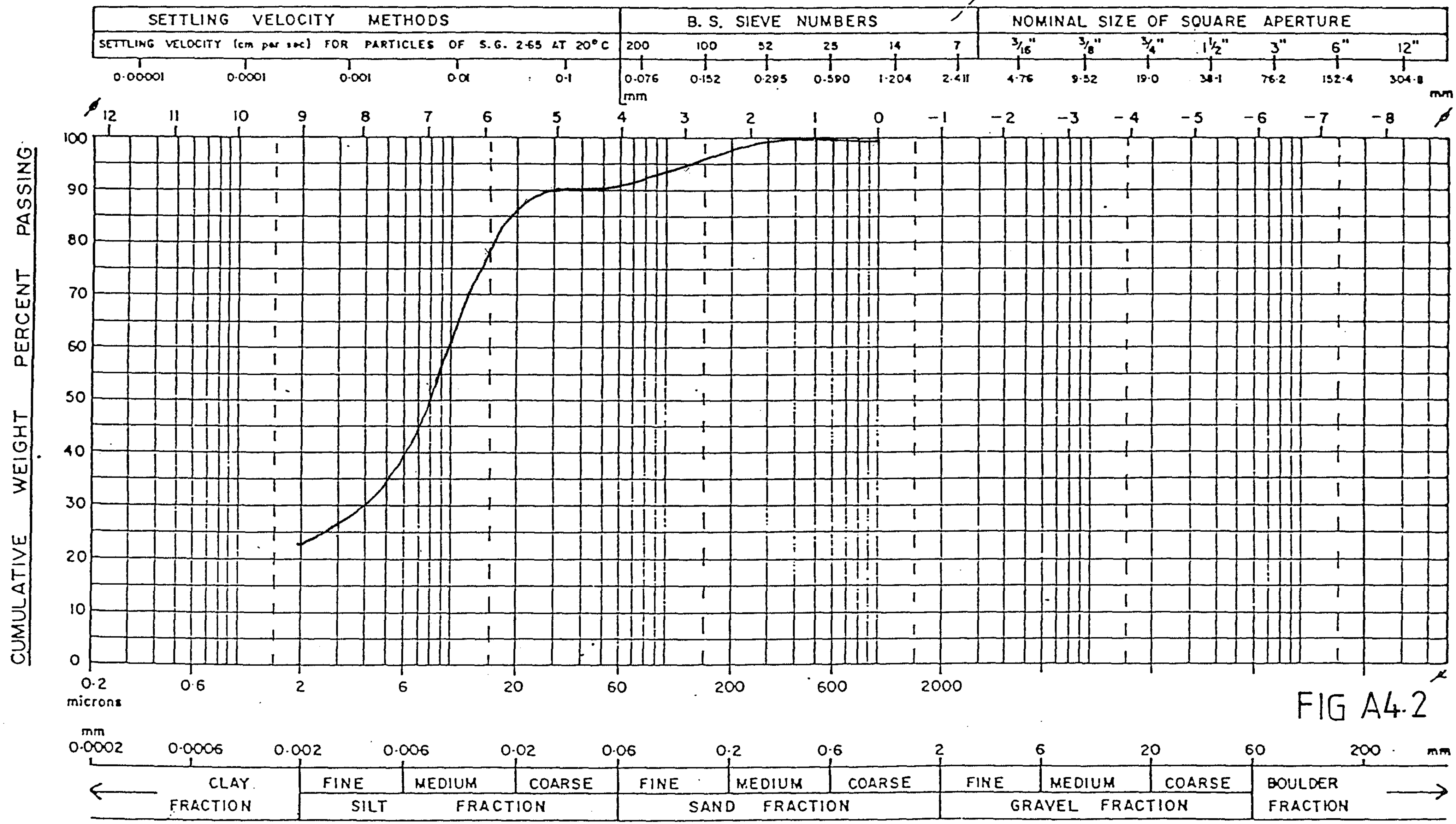


FIG A4·2

PARTICLE SIZE AND CLASSIFICATION.

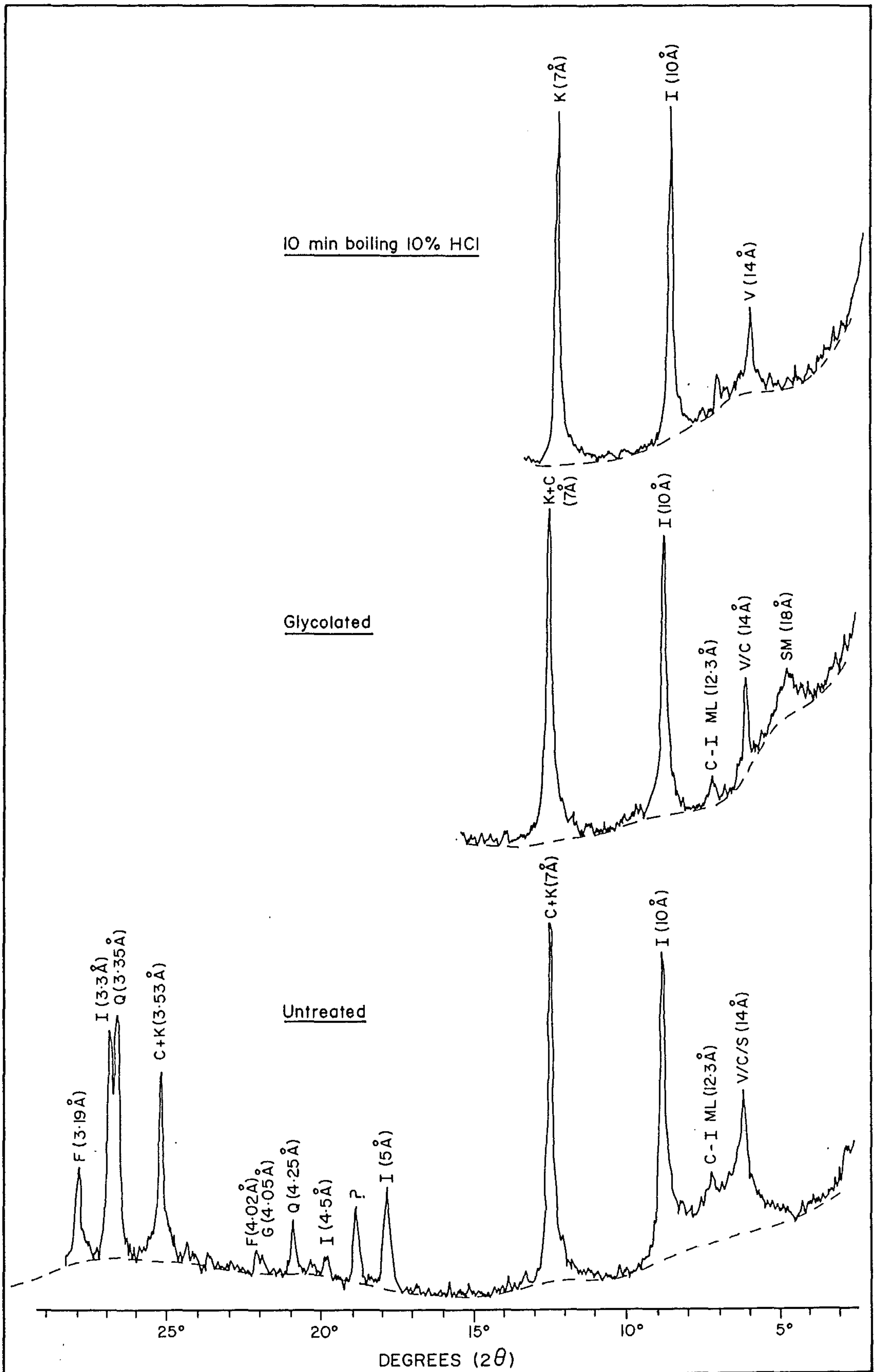


Figure A·4·3 XRD TRACES OF SAMPLES II & III (SHEARBOX SAMPLES)

APPENDIX 5
SHEAR STRENGTH TEST RESULTS

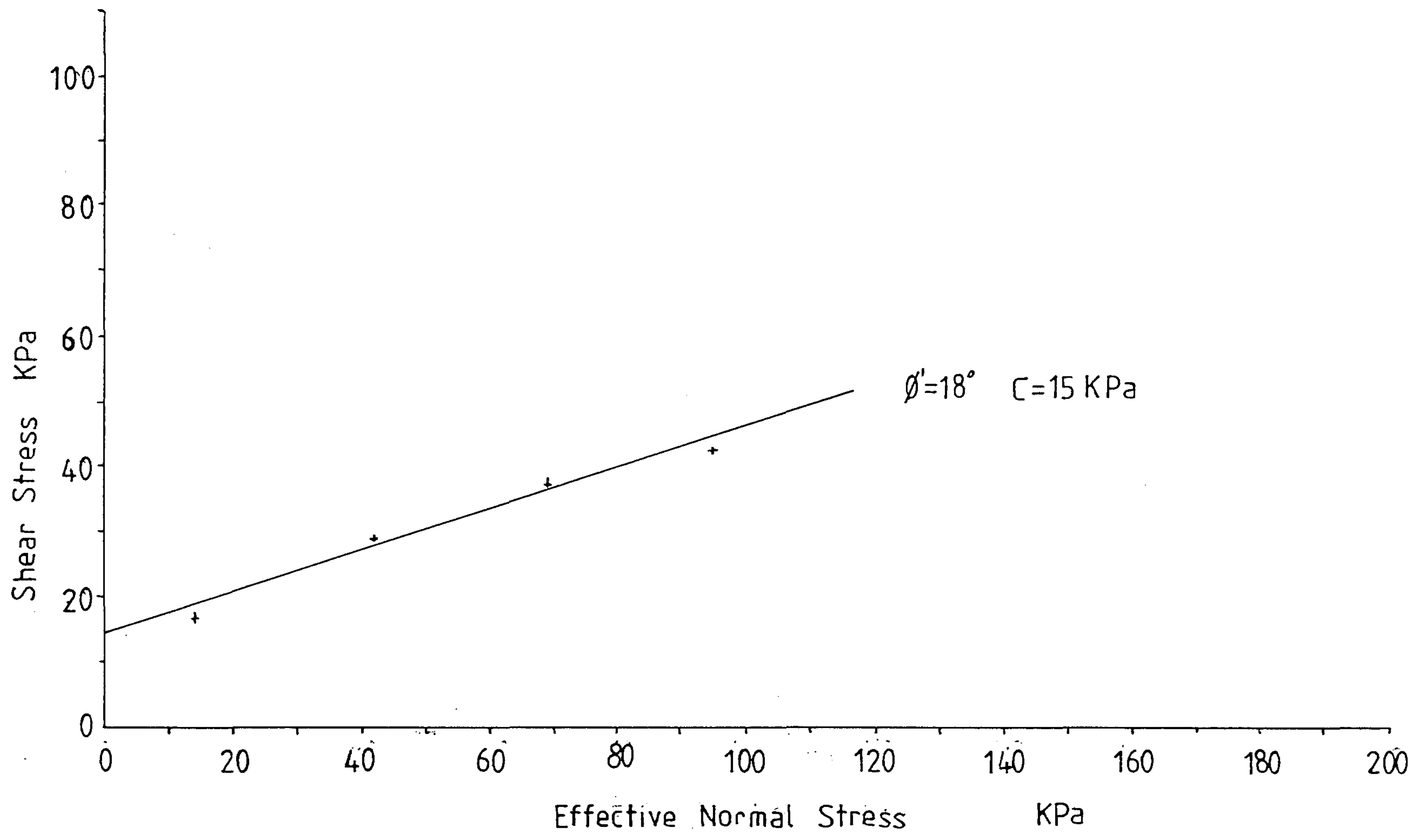


FIGURE A5·1 SHEAR STRENGTH OF SLIP MATERIAL – JUNE'86 CUT BATTER FAILURE

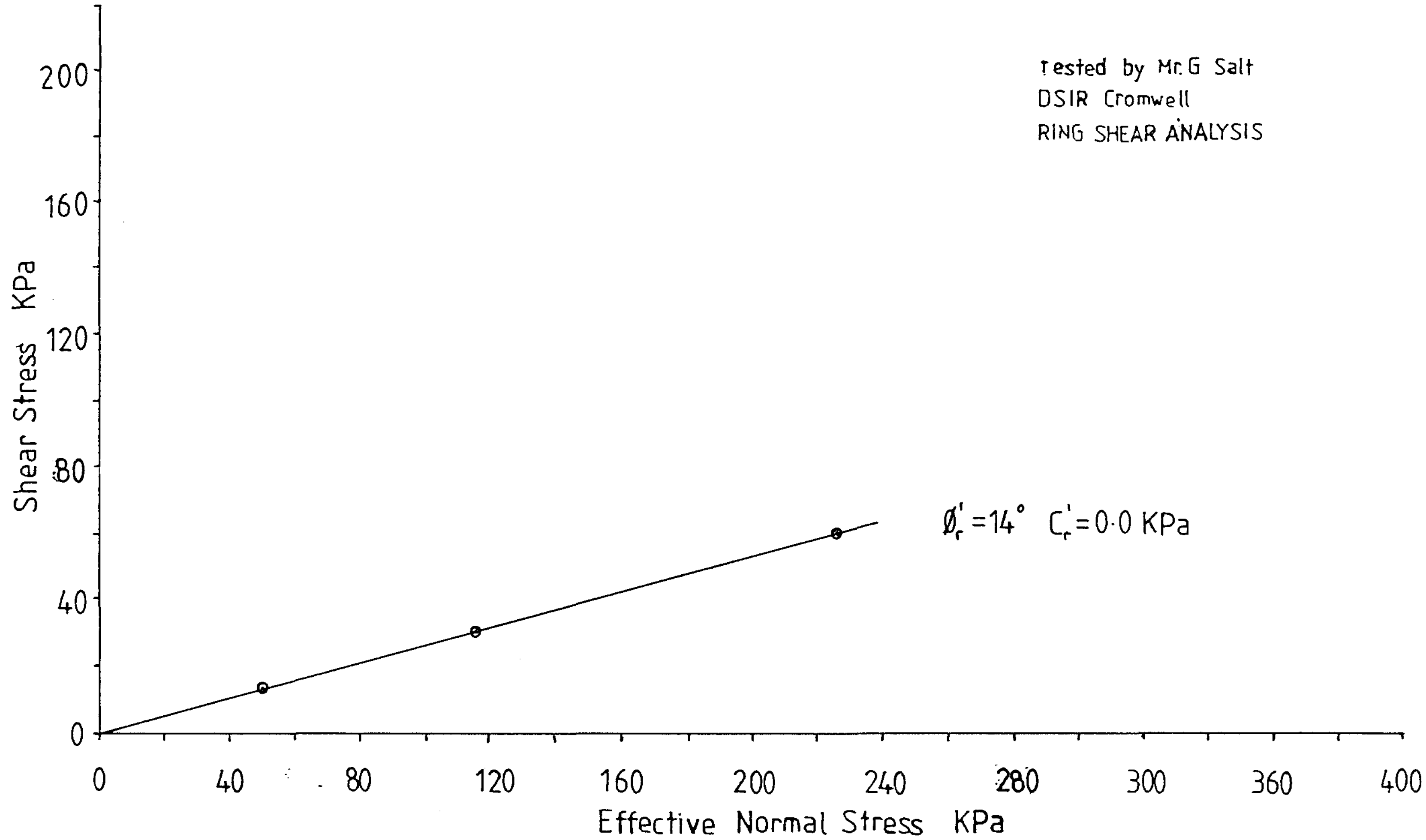


FIGURE A5·2 RESIDUAL STRENGTH OF SLIP MATERIAL – JUNE '86 CUT BATTER FAILURE

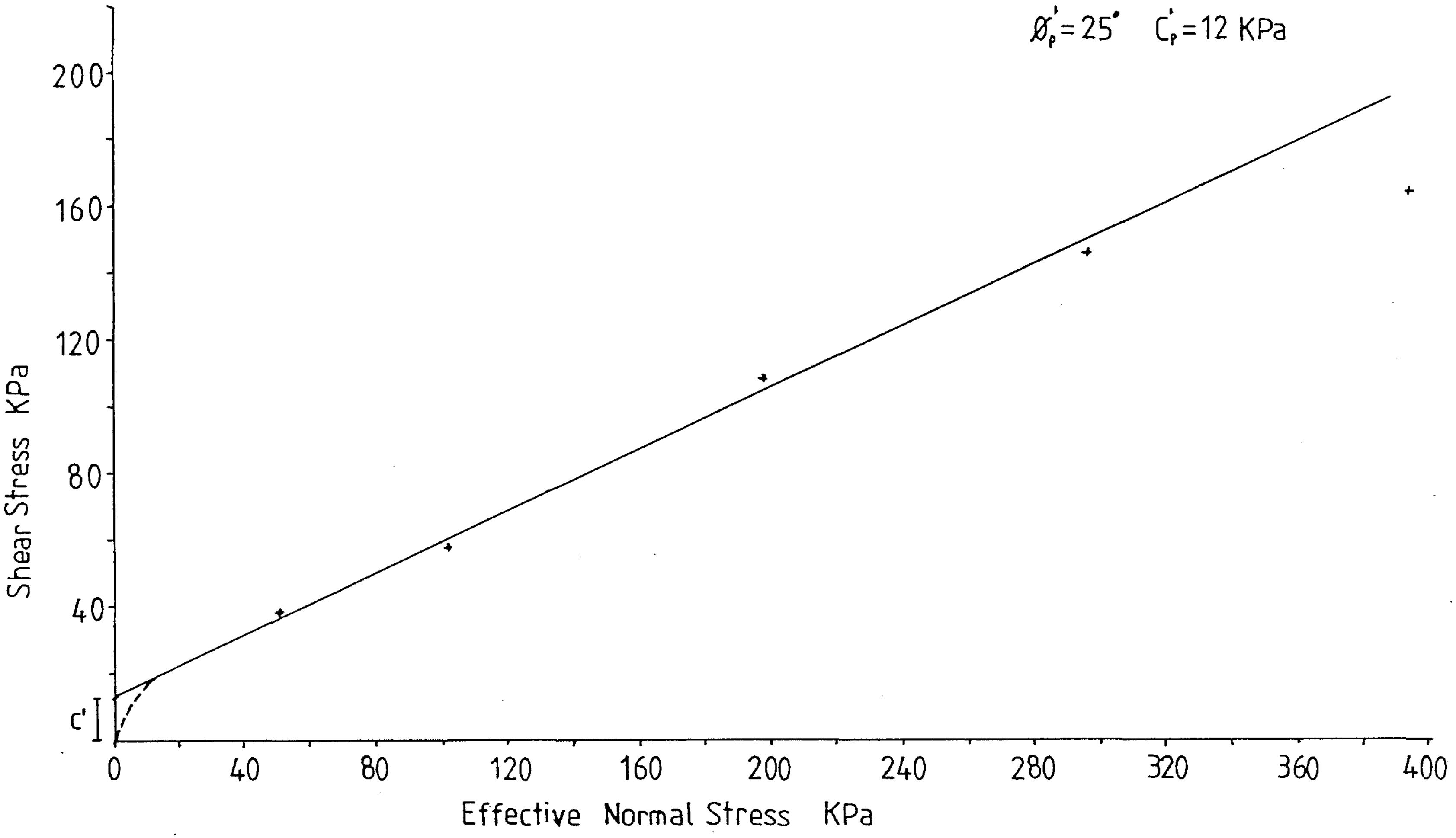


FIGURE A5.3 SHEAR STRENGTH ALONG NATURAL BEDDING PLANE

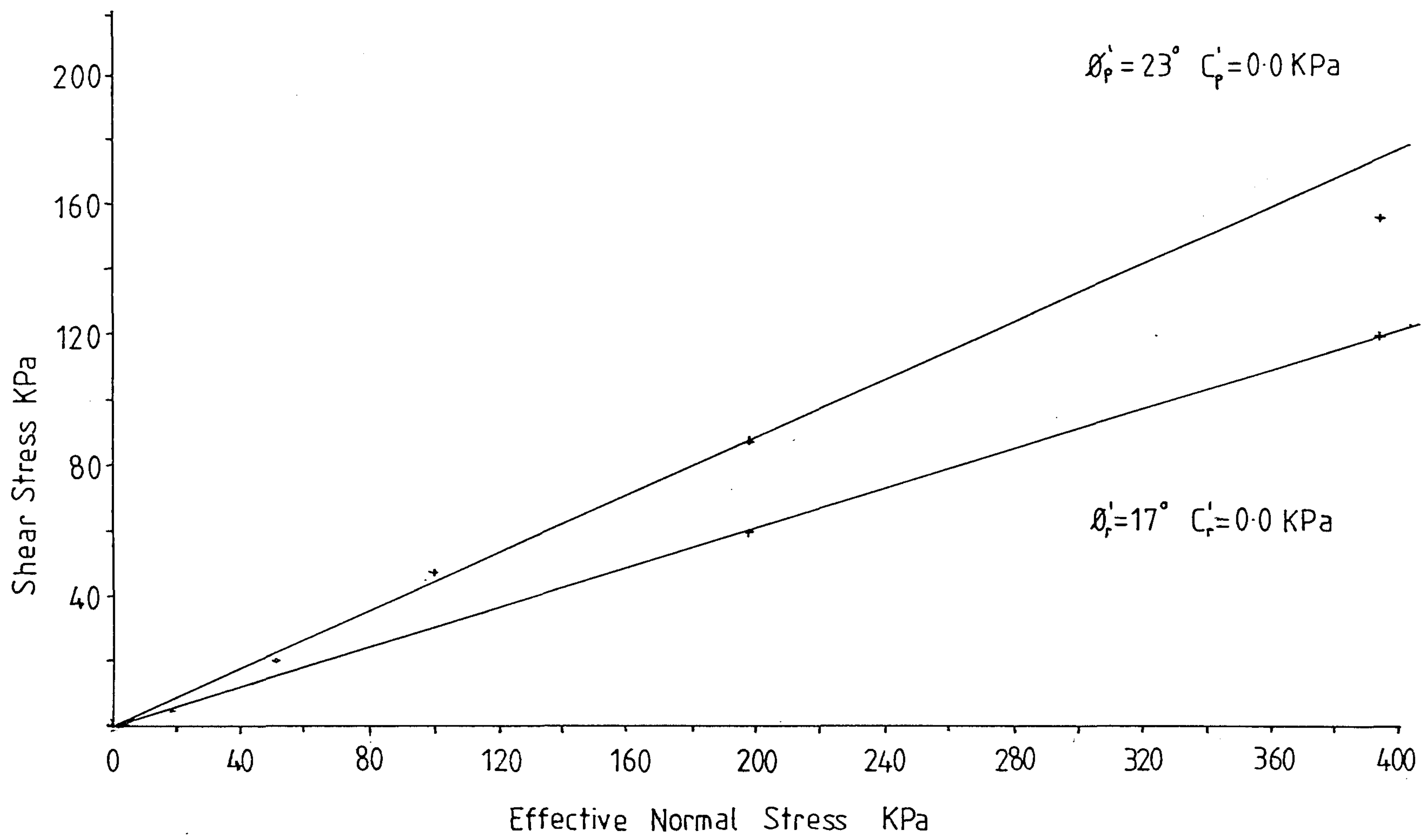


FIGURE A5·4 SHEAR STRENGTH OF SAW CUT VERTICAL JOINT PARALLEL TO HIGHWALL

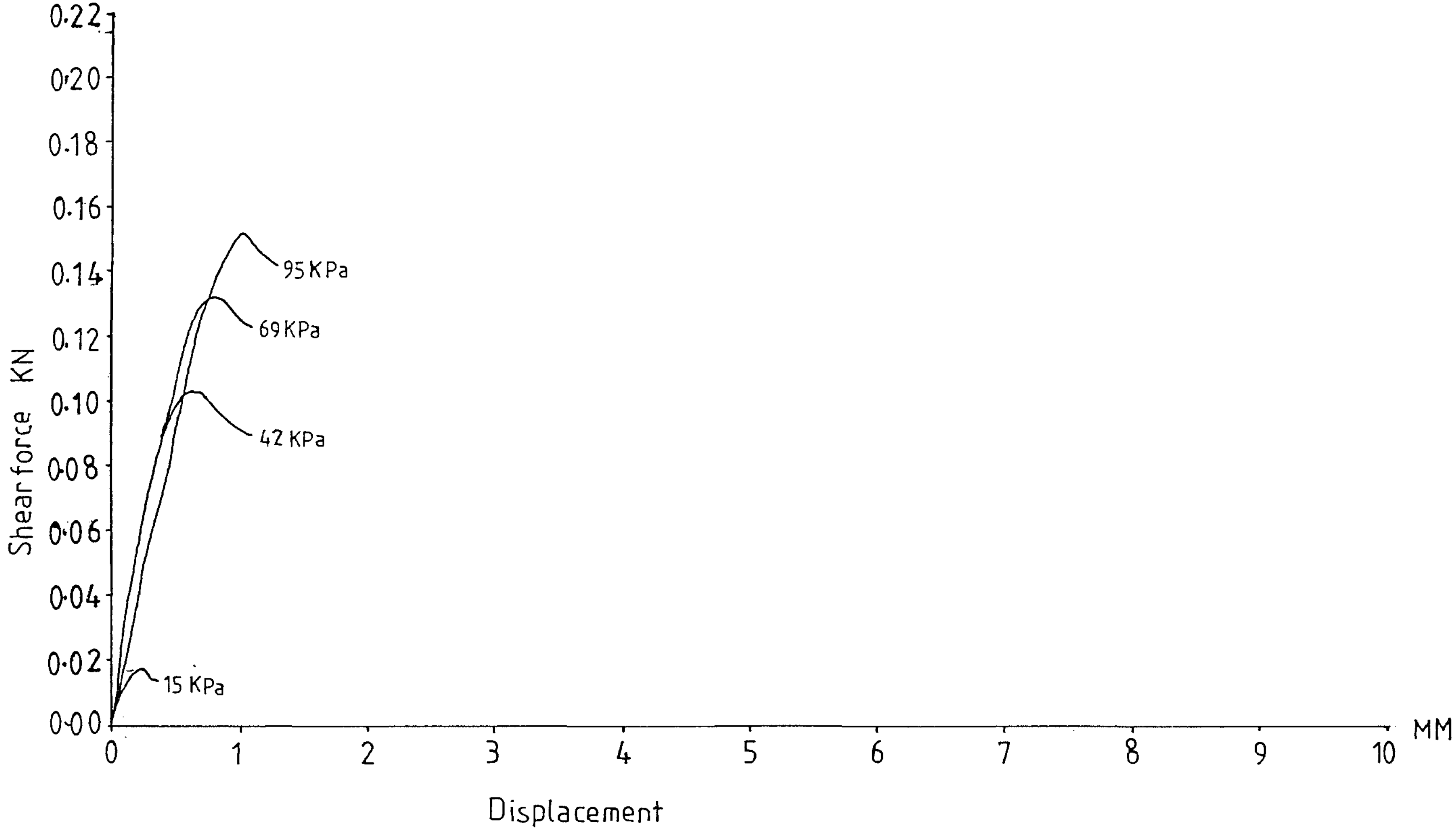


FIGURE A5.5 DISPLACEMENT VERSES SHEARFORCE FOR SLIP MATERIAL

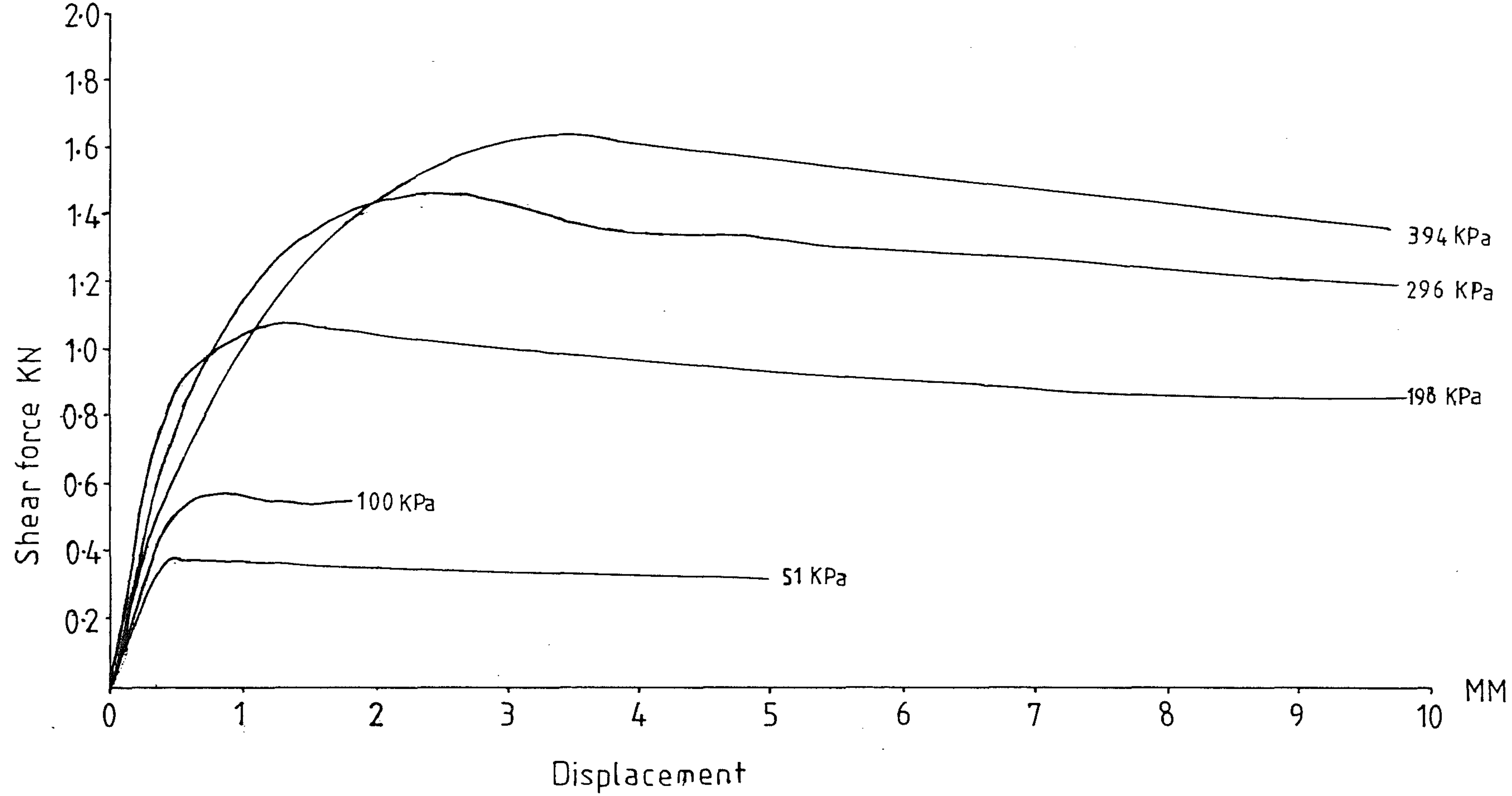


FIGURE A5·6 DISPLACEMENT VERSES SHEARFORCE FOR NATURAL BEDDING PLANE

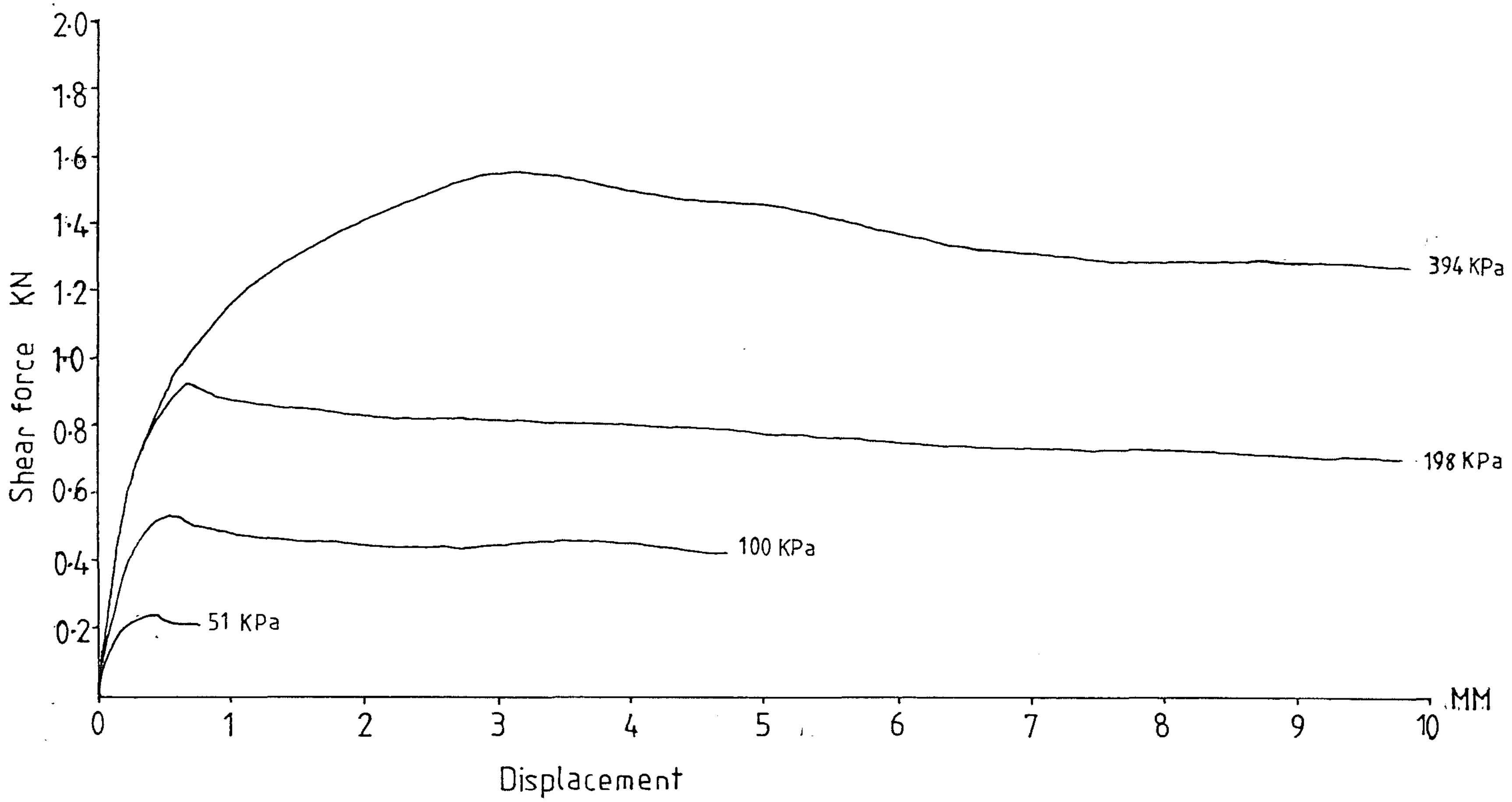


FIGURE A5·7 DISPLACEMENT VERSES SHEARFORCE FOR SAW CUT VERTICAL JOINT

APPENDIX 6
CALCULATIONS FOR WEDGE ANALYSIS

(based on procedure of Hoek and Bray 1981)

Calculations Wedge Analysis.

$\psi_a = 50°$ $\quad$ $\cos\psi_a = 0.6427$

$\psi_b = 56°$ $\quad$ $\cos\psi_b = 0.5592$

$\psi_5 = 39°$. $\quad$ $\sin\psi_5 = 0.6293$

$\theta_{na.nb} = 80°$ $\quad$ $\cos\theta_{na.nb} = 0.1736$

$\sin\theta_{na.nb} = 0.9848$

$\theta_{24} = 124°$ $\quad$ $\sin\theta_{24} = 0.8290$

$\theta_{45} = 48°$. $\quad$ $\sin\theta_{45} = 0.7431$

$\theta_{2.na} = 17°$ $\quad$ $\cos\theta_{2.na} = 0.9563$

$\theta_{13} = 90°$ $\quad$ $\sin\theta_{13} = 1.0$

$\theta_{35} = 54°$ $\quad$ $\sin\theta_{35} = 0.8090$

$\theta_{1.nb} = 54°$ $\quad$ $\cos\theta_{1.nb} = 0.5877$

$\gamma = 20\ \mathrm{kN\,m^{-3}}$ $\quad$ $\phi = 25°$, $\tan\phi = 0.4663$

$\gamma_w = 10\ \mathrm{kN\,m^{-3}}$ $\quad$ $\phi = 30°$, $\tan\phi = 0.5773$

$H = 9\mathrm{m}$ $\quad$ $\phi = 35°$, $\tan\phi = 0.7002$

$$X = \frac{\sin\theta_{24}}{\sin\theta_{45}\cdot\cos\theta_{2.na}} = \frac{0.829}{0.7431 \times 0.9563} = 1.166$$

$$Y = \frac{\sin\theta_{13}}{\sin\theta_{35}\ \cos_{1.nb}} = \frac{1}{0.809 \times 0.5877} = 2.10$$

$$A = \frac{\cos\psi_a - (\cos\psi_b\cdot\cos\theta_{na.nb})}{\sin\psi_5\cdot\sin^2\theta_{na.nb}} = \frac{0.6427 - (0.5591 \times 0.1736)}{0.6293 \times 0.9698}$$

$$= 0.8939$$

$$B = \frac{\cos\psi_b - (\cos\psi_a\cdot\cos\theta_{na.nb})}{\sin\psi_5\cdot\sin^2\theta_{na.nb}} = \frac{0.5591 - (0.6427 \times 0.1736)}{0.6293 \times 0.9698}$$

$$= 0.7332.$$

CASE I ; $c' = 0$, $u = 0$

$$F = A \tan \phi'_A + B \tan \phi'_B$$

assume $\phi' = 25°$: $F = (0.8939 \times 0.4663) + (0.7332 \times 0.4663)$
$= 0.75$

assume $\phi' = 30°$: $F = (0.8939 \times 0.5773) + (0.7332 \times 0.5773)$
$= 0.93$

assume $\phi' = 35°$: $F = (0.8939 \times 0.7002) + (0.7332 \times 0.7002)$
$= 1.13$

CASE II : $c' > 0$ $u = 0$

$$F = \left(\frac{3c_A}{\gamma H} \cdot X\right) + \left(\frac{3c_B}{\gamma H} \cdot Y\right) + A \tan \phi'_A + B \tan \phi_B .$$

assume $\phi = 25°$:

and $c' = 5kPa$: $= \left(\frac{15}{180} \times 1.16\right) + \left(\frac{15}{180} \times 2.10\right) + (0.8939 \times 0.4663) + (0.7332 \times 0.4663)$

$F = 0.0966 + 0.175 + 0.4168 + 0.3418$

$F = 1.03$

and, $c' = 10kPa$: $= 0.1933 + 0.349 + 0.4168 + 0.3418$

$F = 1.30$

and $c' = 15kPa$: $= 0.29 + 0.525 + 0.4168 + 0.3418$

$F = 1.57.$

<u>assume $\phi' = 30°$</u> :

and. $C' = 5kPa$: $\left(\frac{15}{180} \times 1.16\right) + \left(\frac{15}{180} \times 2.10\right) + (0.8939 \times 0.5773) + (0.7332 \times 0.5773)$

$F = 0.0966 + 0.175 + 0.516 + 0.423$
$F = 1.21$

and $C' = 10kPa$: $\left(\frac{30}{180} \times 1.16\right) + \left(\frac{30}{180} \times 2.10\right) + (0.8939 \times 0.5773) + (0.7332 \times 0.5773)$

$F = 0.1933 + 0.349 + 0.516 + 0.423$
$F = 1.48$

and $c' = 15kPa$: $\left(\frac{45}{180} \times 1.16\right) + \left(\frac{45}{180} \times 2.10\right) + 0.516 + 0.423$

$F = 0.29 + 0.525 + 0.516 + 0.423$
$F = 1.75$

<u>assume $\phi' = 35°$</u>

and $C' = 5kPa$: $\left(\frac{15}{180} \times 1.16\right) + \left(\frac{15}{180} \times 2.10\right) + (0.8939 \times 0.7002) + (0.7532 \times 0.7002)$

$F = 0.0966 + 0.175 + 0.6259 + 0.5133$
$F = 1.41$

and $c' = 10kPa$: $\left(\frac{30}{180} \times 1.16\right) + \left(\frac{30}{180} \times 2.10\right) + 0.6259 + 0.5133$

$F = 0.1933 + 0.349 + 0.6259 + 0.5133$
$= 1.68$

and $c' = 15kPa$: $\left(\frac{45}{180} \times 1.16\right) + \left(\frac{45}{180} \times 2.10\right) + 0.6259 + 0.5133$

$F = 0.29 + 0.525 + 0.6259 + 0.5133$
$= 1.95$

CASE III $\quad c' > 0 \quad u > 0$

$$F = \left(\frac{3C_A}{\gamma H} \cdot X\right) + \left(\frac{3C_B}{\gamma H} \cdot Y\right) + \left(A - \frac{\gamma_w}{2\gamma} \cdot X\right)\tan\phi_A + \left(B - \frac{\gamma_w}{2\gamma} \cdot Y\right)\tan\phi_B.$$

assume $\phi' = 25°$

and $c' = 5kPa$

$$F = \left(\frac{15}{180} \times 1.16\right) + \left(\frac{15}{180} \times 2.10\right) + \left(0.8939 - (0.25 \times 1.16)\right)0.4663 + \left(0.7332 - (0.25 \times 2.10)\right)0.4663$$

$$F = 0.0966 + 0.175 + 0.2815 + 0.0971$$
$$F = 0.65$$

and $c' = 10kPa$.

$$F = 0.1933 + 0.349 + 0.2815 + 0.0971$$
$$F = 0.92$$

and $c' = 15kPa$.

$$F = 0.29 + 0.525 + 0.2815 + 0.0971$$
$$F = 1.19$$

assume $\phi' = 30°$

and $c' = 5kPa$ $\quad F = 0.0966 + 0.175 + 0.3486 + 0.1202$
$F = 0.74$

$c' = 10kPa$ $\quad F = 0.1933 + 0.349 + 0.3486 + 0.1202$
$F = 1.01$

$c' = 15kPa$ $\quad F = 0.29 + 0.525 + 0.3486 + 0.1202$
$F = 1.28$

<u>assume $\phi' = 35°$</u>

and $c' = 5\,kPa$ $F = 0.0966 + 0.175 + 0.4228 + 0.1457$

$F = 0.84.$

and $c' = 10\,kPa$ $F = 0.1933 + 0.349 + 0.4228 + 0.1457.$

$F = 1.11$

and $c' = 15\,kPa$ $F = 0.29 + 0.525 + 0.4228 + 0.1457.$

$F = 1.38.$

APPENDIX 7

SARMA NON VERTICAL SLICE ANALYSIS

SARMA NON-VERTICAL SLICE ANALYSIS

Analysis no. 1984 Tauranga Group Failure: failure surface along bedding

Unit weight of water = 10

Side number	1	2	3	4
Coordinate xt	9.40	27.30	32.40	44.20
Coordinate yt	-13.00	1.40	2.90	6.30
Coordinate xw	9.40	27.30	32.40	44.20
Coordinate yw	-13.00	1.40	2.90	6.30
Coordinate xb	9.40	37.60	43.00	44.20
Coordinate yb	-13.00	-11.20	-10.70	6.30
Friction angle	0.00	24.00	24.00	0.00
Cohesion	0.00	0.00	0.00	0.00

Slice number	1	2	3
Rock unit weight	16.50	16.50	16.50
Friction angle	25.00	25.00	24.00
Cohesion	12.00	12.00	0.00
Force T	0.00	0.00	0.00
Angle theta	0.00	0.00	0.00

Effective normal stresses

Base		83.25	163.60	11.28
Side	0.00	30.74	45.00	

Acceleration Kc = 0.0408 Factor of Safety = 1.09

SARMA NON-VERTICAL SLICE ANALYSIS

Analysis no. 1984 Tauranga Group Failure: fail. surf. along bedding

Unit weight of water = 10

Side number	1	2	3	4	5
Coordinate xt	9.40	27.30	32.40	42.00	44.20
Coordinate yt	-13.00	1.40	2.90	5.60	6.30
Coordinate xw	9.40	27.30	32.40	44.00	44.20
Coordinate yw	-13.00	1.40	2.90	3.00	6.30
Coordinate xb	9.40	37.60	43.00	44.00	44.20
Coordinate yb	-13.00	-11.20	-10.70	3.00	6.30
Friction angle	0.00	24.00	24.00	24.00	0.00
Cohesion	0.00	0.00	0.00	0.00	0.00

Slice number	1	2	3	4
Rock unit weight	16.50	16.50	16.50	16.50
Friction angle	25.00	25.00	24.00	24.00
Cohesion	12.00	12.00	0.00	0.00
Force T	0.00	0.00	0.00	0.00
Angle theta	0.00	0.00	0.00	0.00

Effective normal stresses

Base	80.96	161.77	25.70	8.36
Side	0.00	26.49	40.33	15.03

Acceleration Kc = 0.0435 Factor of Safety = 1.10

SARMA NON-VERTICAL SLICE ANALYSIS

Analysis no. 1984 Tauranga Group Failure: fail. surf. along unconformity

Unit weight of water = 10

Side number	1	2	3	4	5
Coordinate xt	6.20	27.30	32.40	42.00	44.20
Coordinate yt	-15.50	1.40	2.90	5.60	6.30
Coordinate xw	6.20	29.30	33.00	44.00	44.20
Coordinate yw	-15.50	-1.00	0.00	3.00	6.30
Coordinate xb	6.20	38.60	43.00	44.00	44.20
Coordinate yb	-15.50	-12.50	-12.00	3.00	6.30
Friction angle	0.00	24.00	24.00	24.00	0.00
Cohesion	0.00	0.00	0.00	0.00	0.00

Slice number	1	2	3	4
Rock unit weight	16.50	16.50	16.50	16.50
Friction angle	18.00	18.00	24.00	24.00
Cohesion	15.00	15.00	0.00	0.00
Force T	0.00	0.00	0.00	0.00
Angle theta	0.00	0.00	0.00	0.00

Effective normal stresses

Base		105.24	183.50	25.04	7.71
Side	0.00	50.73	55.99	14.50	

Acceleration Kc = -0.0013 Factor of Safety = 1.00